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THE ROAD
TO MODERN SCIENCE

The Road To Modern Science

By

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To

W. R. and K. R.

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FOREWORD

The primary object in writing this book was to present the story of scientific discovery in a form which would appeal to intelligent boys and girls. The subject-matter of the majority of the books on the history of science is, in the main, too difficult for such readers. On the other hand, in those books which tell only the story of the lives of a few great scientists, the broad view of scientific discovery, as a whole, tends to be obscured.

While the audience I have had in mind has, therefore, been youthful, I hope very much that this book may also appeal to more adult readers for whom the scientific achievements of this modern world have not lost all their wonder, and who may like to read the story of what went before.

I should like to thank Miss C. M. Waters, B.A., and Miss E. C. Underwood, B.A., for much helpful advice and criticism of the text.

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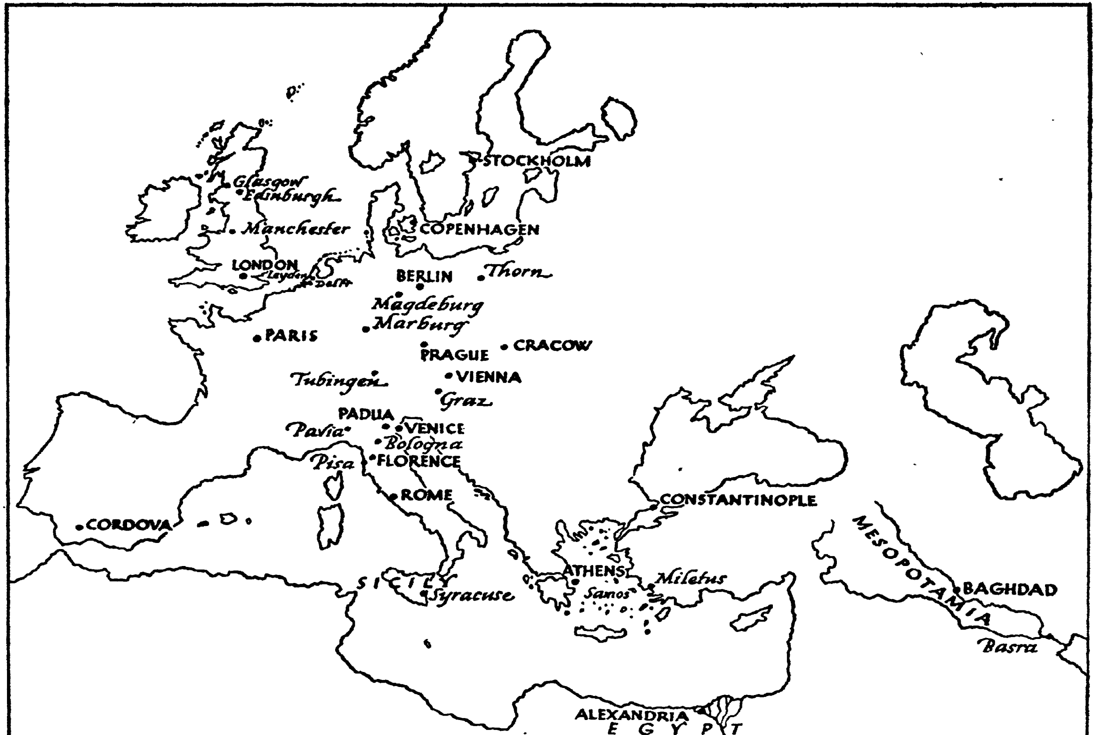
Illustrated Time-Charts will be found at the beginning and end of the book.



MAP SHOWING PLACES OF IMPORTANCE IN THE HISTORY OF SCIENCE

PART I

CHAPTER I

The Trail Begins

MANY trails have been blazed since man first made his appearance on earth some hundreds of thousand years ago. Some of these have petered out long ago; others have merged together into wide roads which have run through the centuries and are now the main thoroughfares of our modern life. The trail which we are going to follow in this book has become perhaps the widest and most important of all others during the last three centuries. I mean the great Highroad of Modern Science. The road is still being made, wide and straight and filled with traffic. Some of the wise people who are watching its progress are asking 'Where will it lead—to a good end or to a bad?' That is a question that not only the makers but the users of the road must consider.

Now what really is Science? The word 'science' means 'knowledge,' so that in its broadest sense it means *all* the knowledge that man has gained, arranged in an orderly manner. Thus everything that you learn in school is really Science. We generally use the word, however, with the more limited meaning of our knowledge and understanding of the world around us as it is shown to us through our various senses. Notice that knowledge can only be called 'science' when it is *orderly*. Man gained a great deal of knowledge before he began to think about it as 'knowledge'; that is, to arrange and

classify it, to notice similarities and differences between various parts and so to make 'general statements.'

Now imagine that you do not live in the twentieth century but far back in prehistoric times. You are really almost an animal, but you are not quite, because you have a better brain than an animal, one which has the power to 'reason,' though only in a very elementary fashion. You have also a much more definite memory than an animal. You probably live in a cave with a tribe of other prehistoric people like yourself and you have to hunt for your food and protect yourself from other animals. That is your main business in life. Now because you have a better memory and because you can reason things out a little, you make a rather better business of living than the animals. You gradually rely more and more on your brain and less on your physical powers in order to escape the big animals and to kill the others for food. You find, for instance, that you can make a weapon out of a flint at the end of a wooden pole, which can do more harm than your teeth or claws, and which, at the same time, can keep you more out of range of the animal you are fighting. So gradually you accumulate a great many bits of knowledge that are very useful to you in your business of living. But each bit is quite separate from every other bit, and you only think of it as applying to the particular circumstances in which you first learnt it.

Two of the most important things that happened to primitive man were his beginning to talk and his beginning to count. The latter probably happened very much later than the first, and it is with this event that our trail really begins. Let us try to imagine how it happened.

At first, a prehistoric man fishing for his family would

go on fishing until each of the, say, five of them had a fish; but he could not go down to the river and catch 'five fish' unless his family were there to be given them in turn, until each had one. Later he learnt to count 'five fishes' or 'five stones,' but saw no connection between the two. Finally, however, on one of his descendants this connection dawned, and he realised that one, two, three, five, etc., had a meaning apart from the fishes or stones to which they had always been attached. That man, whoever he may have been, was the first pioneer to start blazing the trail which was to wind, now clear, now faint, now broad and straight, now narrow and tortuous, till the great giants of the sixteenth century tracked their way through the undergrowth which had grown up and made our modern high road. As we look back upon the makers of the road we see that perhaps the most useful tool they had for their task was this knowledge of counting and number, which was first fashioned, crudely and roughly, by our unknown prehistoric man.

For many thousands of years man went on accumulating knowledge and using it for his business of living. He stopped living in small tribes and built himself cities and lived in large communities. In other words, he gradually became civilised. He still, however, only used his knowledge for the practical business of living and enjoying life. He had all sorts of luxuries; he learnt how to hand on his knowledge by writing; but everything he learnt or did had a practical end in view. He never found out things just for the sake of knowing them. The first people to pursue knowledge for its own sake were the Greeks, and with them 'Science' really has its origin. But in the efforts of the Greeks to bring all the

knowledge that man possessed into one big orderly whole, they had, to help them, all the knowledge gained by the men who had lived on the earth before their time. Thus, although it is only when we reach the Grecian Era that we find the signpost 'Science,' the trail is to be found if we look for it, winding from our prehistoric man through the time of the ancient civilisations to the foot of the signpost.

CHAPTER II

Through the Ancient World

THERE were three great races of people from whom the Greeks learnt their knowledge. They were the Egyptians, the Babylonians, and the Phœnicians; and they were all in a flourishing state during the years 1000 B.C. to 500 B.C., during which time the Greeks were gradually winning for themselves a strong position on the north-east coast and islands of the Mediterranean Sea. Let us see just what kind of a life these three nations lived at that time and what was the most important contribution of each to the knowledge which was the heritage of the Greeks.

The Egyptians.—The civilisation of the Egyptians is one of the oldest civilisations on the earth. These people lived on the banks of the Nile and the small strip of fertile country on either side. This fertile land they cultivated, and grew there a great many crops of much the same kind that we grow nowadays. Besides food-crops, they also grew flax, and, from the thread spun from this, they wove themselves linen garments and dyed them many beautiful colours from dyes which they learnt to make. They also grew the Papyrus grass, from which they made paper to write on, and thus left records of their doings which people living afterwards have found and read.

Now every year the Nile floods its banks because of the tropical rains which fall in the region where the river rises. This makes the land round it very fertile, but it also meant, at that time, that every year the fields on its banks had all their boundaries wiped out, so that the

land had all to be divided out again when the floods subsided. It was, therefore, very necessary for the Egyptians to have some way of measuring up the land, in order that after the flood each should have his right amount again. The land was measured out in rectangles, and a tax was paid to the King on each rectangle of a certain size. Now it was easy enough to measure the lengths of the sides of the rectangles, but it was not so easy to make the angles between the sides really right

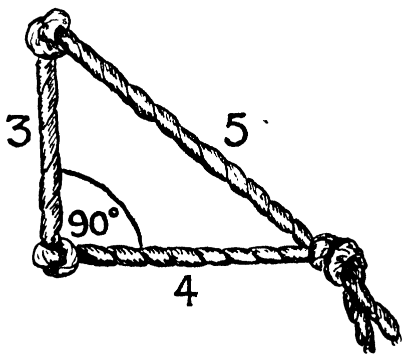


FIG. 1

angles. Remember that there were no protractors and geometry had never been heard of. However, the Egyptians discovered, practically, a very important bit of knowledge, which was, that if a rope of twelve units in length is divided by knots into sections of three, four, and five units and made into a triangle with the knots at the corners, then the angle opposite the side of five units is always a right angle. This is a special case of one of the theorems in geometry, but the Egyptians only knew it as a fact of experience, and, as far as we know, did not bother their heads as to 'why.' It was not until a long while later that a Greek, named Pythagoras, whom we

shall talk about again, realised that other lengths for the sections would also give a right angle provided that the lengths are related to each other in the special manner demonstrated in Pythagoras' theorem. Pythagoras was a *scientist*, but the Egyptian 'rope-stretchers,' as the land-measurers were called, were not.

The buildings of the Egyptians also show that they had great skill in practical measurement and construction, and their 'right-angle device' was used in building and orientating their temples. The most famous of their buildings were the great Pyramids or tombs in which they buried their kings. The fact that they have lasted about four thousand years shows how well they must have been built. These Pyramids, when measured to-day, are found to be very accurately constructed. The angles at the base are all almost exactly 52°. The Egyptians, of course, had no machines, and yet they were able to lift the great masses of stone of which the Pyramids were made to a height of 500 ft., higher than the cross on top of St Paul's Cathedral. This they did by means of ropes, pulled by a great army of slaves, and possibly by the aid of levers; but you must realise that they knew nothing about the 'lever law' which was discovered much later by another Greek, Archimedes.

One of the things which the Egyptians were the first to do was to invent a calendar. The earliest known date in human history is 4241 B.C., when the Egyptian calendar was invented. The man who devised this calendar knew that the sun took three hundred and sixty-five days to complete the circle of the seasons; and that the moon went round the earth in twenty-eight days. This shows that the Egyptians must have watched the movements of the sun and moon very carefully. Their

records also tell us that they watched the stars as well, calling certain of them by definite names and picking out groups of them which seemed to form pictures. These are what we now call the constellations, and our names for them mean the same as did the old Egyptian names.

The Egyptians did not just stay quietly in their lands on the banks of the Nile. They built themselves ships, and in these they ventured down the Nile into the Mediterranean; and, by cutting the first Suez Canal, they sailed through to the Red Sea. In this way they traded with, and at one time conquered, other civilised nations, and later on were in their turn conquered. So they obtained more knowledge, not by discovery for themselves, but by copying what they saw being done by those other nations.

The Babylonians.—The chief race of people with whom the Egyptians came in contact were the Babylonians who inhabited the land between the Euphrates and the Tigris, which we now call Mesopotamia. In most ways the civilisation of the people dwelling in Mesopotamia was very much the same as that of the Egyptians. They cultivated the land; wove and embroidered their clothes; built themselves cities and palaces; and made laws which they wrote down, so that we find them to-day.

Babylonia was not quite so fertile a land as Egypt, nor was the climate quite so good. To water the land away from the river they therefore built canals, and so were the first people to use irrigation. Again, unlike the Egyptians, they had not great quantities of building stone in their land. Instead, they made bricks out of clay and baked them in the summer sun. These bricks were not as lasting as stone, and so we do not find their buildings still standing entire to-day.

They also used clay to make tablets on which to write. They probably began by picture writing, using a reed to mark the clay; but this did not make good pictures, so that they soon took to using symbols, something like this Y-<. Whole libraries of these tablets have been found, and these tell us a great deal about the life of the Babylonians. They were quite good at counting, and at arithmetic, but they did not usually count in tens, as we do, but in sixties. Thus, suppose that (in their writing) they wrote a number such as 16; the 1 would not stand for ten but for sixty, and the number would therefore be sixty-six not sixteen. Our division of the hour into sixty minutes, and the minute into sixty seconds, dates right back to the days of Babylon.

Amongst the things which have been dug out of the ground in the land of the Babylonians are a number of very beautifully worked chains and vessels in gold, silver, and bronze. We know, therefore, that they must have had very skilled metal-workers amongst them. Now the discovery of metals, and of how to use them for making weapons and vessels, was one of the most important discoveries in the history of man. At first, as you know, man made himself weapons of flint and stone. Copper was probably discovered by the Egyptians first. Perhaps some Egyptian traveller on the Sinai peninsula made a fire and built it round with bits of rock which he found lying about. In the morning, when he raked out the fire, he found among the ashes hard shiny, red beads of copper. What had happened? Nowadays, we get a very great number of metals out of the ground and use them for all sorts of purposes, but only a very few of them look like metals when they are in the ground. Before they can be used, the rocks containing them have to be

treated in some way, and nearly always, at some stage, they have to be heated with carbon either as coke or charcoal. This process is known as smelting. Now you will see how that old Egyptian got his copper. The hot charcoal from his fire acted on the rocks surrounding it and produced the metal copper. At first he probably only used these metal beads as ornaments, but when he discovered how hard they were he would try to get more with which to make weapons or vessels.

Now copper melts at a considerably lower temperature than a metal such as iron, and so it was quite easy to melt the copper and so to make it into any shape that was wanted. It can also be won from the rock containing it, at a much lower temperature than iron, and that is probably why it was discovered so long before. Gold, silver, and tin were discovered somewhere about the same time as copper, but gold and silver are too soft to be of very much use by themselves for anything but ornament. A method of hardening copper still further was discovered when the metal had been in use sometime under a thousand years. This was done by melting a little tin with the copper and making the alloy known as bronze. For very many years this was the hardest and strongest substance known, and all weapons were made of it. From the many articles of bronze, copper, gold, and silver that have been found in Babylonia, it is clear that the old inhabitants of that land must have been greatly skilled in all kinds of metal work.

I have left it until the last to tell you about that thing for which the Babylonians are most famous: that is their study of the stars. They seemed to have noticed that things on earth began to grow when the sun, at midday, was a certain height in the sky. They saw, also, other changes on the earth, and noticed changes in the moon

and stars occurring at the same time. From this the idea grew up that the sun, moon, and stars really controlled the happenings on earth. It therefore seemed to them very important to study the changes in these heavenly bodies, so that they might glean from them some information as to what was likely to happen on earth. Accordingly, their wisest men spent their lives in watching the sky, recording all changes and making star-maps. The magi of the Bible were probably three of these wise men of Babylonia. Notice that they did not study the stars just for the sake of knowing about them, but because they thought that from their changes they could foretell future events on the earth. These men were what are known as Astrologers, while the men of to-day who study the stars, for the sake of knowledge alone, are called Astronomers. Nevertheless, the records of these old Babylonian astrologers have been very useful to later astronomers, because most of the changes in the sky are very slow, and so it is of great value to have records of what the sky looked like thousands of years ago.

The Babylonian astrologers picked out the five planets: Mercury, Venus, Mars, Jupiter, and Saturn; and these five 'wandering stars,' with the sun and the moon, were supposed to play an extremely important part in the lives of men. Like the Egyptians, they had also names for various constellations or groups of stars. Now, each day the sun at noon occupies a slightly different position among the stars, and during the year it apparently traces out a huge circle in the heavens. The constellations which lie on this circle were supposed to be of especial importance, and the representations of them are still known as the signs of the Zodiac.

From their observations of the sun in its course across

the sky, the Babylonians made the first clock. It was known as a water-clock or clepsydra. They allowed water to drip regularly from a large vessel, and the moment the sun's upper rim began to appear above the horizon

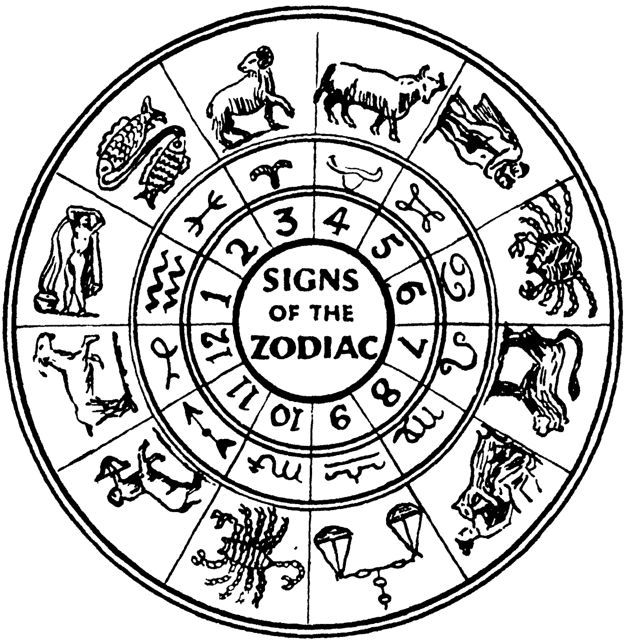


FIG. 2

they began to collect it. Directly the whole of the sun was above the horizon they changed the vessel and went on collecting until the sun just began to appear above the horizon next day. By dividing the water into equal parts they thus had a means of dividing the day into equal parts and so first began to reckon time.

The Phœnicians.—At the time of the rise of Greece the Phœnicians were the great traders of the world. They were only a small nation, and from some points of view

might not be considered so worthy of mention as other small nations existing at that time. It is because of the great part they played in spreading knowledge that I am mentioning them here.

The Phœnicians lived on the narrow fertile strip on the west of Asia Minor, just north of Palestine. In their country were the famous cedars of Lebanon, and from these trees they built themselves ships and traded all round the Mediterranean, even through the Straits of Gibraltar and round the coast of Spain as far as Cornwall. On the mountains behind their coast they reared sheep, and from the wool wove cloth. They were especially clever at making dyes and with these they dyed the cloth they wove.

The important discovery of how to make glass is sometimes attributed to the Phœnicians. They certainly knew how to make it and traded in it with the countries they visited. The story goes that some Phœnician sailors making a fire on a sandy shore, built the fire round with bits of stone which probably contained lime and natron (soda). On raking the ashes they found not copper this time, but glass; for lime, soda, and sand are what we now use to make glass. As a matter of fact, glass was probably made for the first time long before the time of the Phœnicians, but that is very likely the way in which it was first made.

The Phœnicians also became very expert metal-workers, and this was perhaps the basis of their most important trade with the more uncivilised parts of western Europe. They guarded the secret of their skill very jealously, however, and would only hand on the lore to their own race. Many of them settled in different parts of Europe and became the smiths of the countryside. Cornwall,

being so rich in mineral wealth, soon had a Phœnician smith to almost every tribe, and to-day, if you go to Cornwall, you may meet people who proudly claim to be descended from the Phœnicians.

. . . .

Let us now take a wide view at the world about 1000 B.C. and during the next few centuries. Asia was the centre of civilisation. Almost all of the southern part of that continent [1] was inhabited by civilised people—that is, by people who had, to a great extent, learnt how to control the natural world around them and to live a life in which there was room for leisure. There was intercourse of trade and war between the various nations, and in both ways knowledge was spread amongst the peoples. But everywhere we see this knowledge being applied to practical purposes and being valued only for the part it played in contributing to the safety and comfort of man. As more knowledge was accumulated, so the people grew in luxury and wealth. But no new ground was broken, and superstition prevented any step forward. These were not the people who were to strike out into the unknown and blaze new trails in search of greater things.

[1] I have not especially mentioned India and China here—not because they were not important centres of civilisation at that time, but because the paths of knowledge made by them never joined up with the path which eventually led to our modern high road of science.

CHAPTER III

Into a New World

We have already seen that copper was discovered and used a long time before iron. The discovery of the latter and of how to weld it into weapons happened somewhere about 1200 B.C. About this time a new race of people settled on the shores of the Ægean Sea in the land known to them as Hellas, but to us now as Greece. It has been suggested that these people were greatly helped in the conquest of the inhabitants of that country by the use of weapons made of the new metal, iron. Whether or not the Greeks did thus truly usher in the 'Iron Age,' it is quite certain that they brought to the civilisation round the Mediterranean Sea a new age of the mind—the Age of Science, of the desire to understand and to explain everything that they saw happening round about them.

Until about 700 B.C. the Hellenes were occupied in establishing themselves in the land, and fighting, one state with another. By this date, however, a number of prosperous city states had been established, and most of the islands in the Ægean Sea had been colonised. Of these island colonists the Ionians are particularly famous, and to them belonged Thales, the first of the long line of Greek philosophers or 'seekers after the ultimate truth.'

Thales.—Thales was born in Miletus in 624 B.C. Like many of his countrymen he was originally a prosperous merchant and traded chiefly in salt and oil. In this way his business took him abroad a great deal, and especially to Egypt. Now while in that country he became very

much interested in the practical knowledge of the Egyptians, more especially in their methods of land measurement, and in their observations of the stars. He therefore collected as much information as he could, and when he got home he gave up his business as a merchant and devoted the rest of his life to 'philosophy.' One of the first things he realised about the Egyptian rules for land measurement was that they were only special cases of much more general rules. These 'general rules' which he stated were the true beginnings of the science of geometry. One particular theorem which Thales stated and proved was the one about angles at the base of an isosceles triangle always being equal. Once started on geometry the Greeks took to it like ducks to water, and there is very little of the geometry learnt at school which did not originate from them.

Another interesting thing to note about Thales is that, as far as we know, he was responsible for the very beginning of our knowledge of electricity. He found that when amber is rubbed it can attract small light things to it, or, as we now say, it becomes electrified. Now the Greek word for amber is 'electron,' and so all our words of that root can be traced back to Thales and his experiments with amber. He also possessed a bit of lodestone, which is a naturally occurring magnet, and he found out many of its properties.

Perhaps the most important thing of all to remember about Thales is that he was one of the very first men to ask the question: 'What is everything made of?' This question was, perhaps, more discussed than any other by Greek philosophers. Although a variety of answers were given, it was fairly unanimously agreed that the different things found round about them were made up from just

a few simple substances which were called 'elements.' Thales himself said that all things were originally produced from water. Now, it is very interesting to note that, at the present time, scientists have come back to the old Greek idea that all matter is really made up from one elementary substance. We know now that Thales was quite wrong in thinking that substance to be water, but in one way he was nearer the truth than were our scientists some sixty years ago when they thought that there were about seventy or eighty different kinds of elements with nothing common to them all.

Thales, as well as studying philosophy, on his own account, also taught his conclusions to others. Some of these themselves made important contributions to the knowledge of their day, and in their turn had pupils of their own. In this way the love of philosophy spread, and everywhere through Greece we find men questioning and seeking explanations of all that they saw about them. Here, indeed, was a race of road-makers, continually breaking fresh ground and pressing on into the unknown. We can only mention one or two of the most famous of the Greek philosophers, and only those who were most interested in what we now call Science. The next one we shall take is one whom we have already mentioned, namely, Pythagoras.

Pythagoras.—Pythagoras was also an Ionian and was born in the island of Samos in 580 B.C. Like Thales he travelled to Egypt and also perhaps to Babylon, and thus became familiar with the ways of the people of those lands. On his return he settled in southern Italy, which by that time had become a Greek colony. Here he became famous. Many people came to learn from him and a kind of brotherhood was formed. Before joining the brother-

hood everyone had to take certain vows, some of which were definitely religious. All vowed to live a simple and austere life. It is interesting to find that women were admitted to this brotherhood, and the wife of Pythagoras was an important member.

We, however, are only concerned with the contributions of Pythagoras to Science. We have already attributed the beginning of geometry to Thales, but Pythagoras is definitely the founder of the Science of mathematics as a whole. He was more interested in 'numbers' than in anything else, and he thought that the numbers connected with any object were the most essential part of it. 'Ten' he called the perfect number, because $10=1+2+3+4$. 'Three' was the sacred number; it was the number of the universe, because everything has its beginning, its middle, and its end. If you think of the well-known theorem of Pythagoras you will remember that it is the theorem where numbers play the most important part. Since he was so fond of numbers you will not be surprised to hear that Pythagoras first introduced a proper system of weights and measures.

The study of the theory of sound was first begun by Pythagoras. The story goes that one day, while passing a blacksmith's shop, he was attracted by the musical notes emitted by the anvil on being struck by the hammer. This led him to investigate the notes produced by strings of various lengths and thickness, and he found that if he had two similar strings, but one twice as long as the other, the short one produced a note which was an octave higher than the other. If the ratio of the lengths was $3:2$ the interval was a fifth, while with lengths of $4:3$ a fourth was produced. Again he got back to his magical series one, two, three, four, and the idea of harmony and proportion

in everything. Following up the same idea, he pictured the universe as having a central fire around which the sun, the earth, and the planets revolved with varying speeds, each creating its own celestial note, according to its distance from the central fire, and all together giving rise to the 'music of the spheres.'

Like Thales, Pythagoras sought an answer to the question of the structure of matter. He, however, held the theory that all matter was made, in varying proportions of four elements—earth, air, fire, and water. This is known as the famous 'four element' theory which held sway until the end of the Middle Ages. The teachings of Pythagoras had more influence than those of Thales, and, in fact, were only eclipsed by those of the great Aristotle himself.

Hippocrates of Cos.—Before we come to Aristotle there is one other Greek philosopher whom we must mention. This is Hippocrates, known as the 'Father of Medicine.' He was born in the island of Cos in 460 B.C. Like Thales and Pythagoras he travelled extensively over the countries bordering the eastern Mediterranean.

Up to this time, if a man were ill it was thought to be an infliction of the Gods, and that the only remedy was to appease them by offering sacrifices. Thus the chief people concerned in the healing of sickness were the priests of the temples. Now, Hippocrates taught that sickness was due to something wrong in the working of the body, and not to an external cause such as the displeasure of the Gods. To be able to cure the disease, he said, one must study the patient and find out what is causing the trouble. This, of course, is just what doctors of to-day try to do. Hippocrates' theory was that there were in the body four humours or juices—blood, phlegm,

yellow bile, and black bile. When these were present in the right proportions and properly mixed, then the body was healthy; but if the proportions were incorrect, then illness resulted. Now, although this is now known not to be the true explanation, it was the one held by all doctors until about four hundred years ago, and it certainly was nearer the truth than the supernatural one believed up till then.

Hippocrates was the first to propound what is, nowadays, a very favourite maxim: 'Nature is the best of all healers'; and his chief method of cure was a regulation of diet. So Hippocrates thus well deserved the title 'Father of Medicine,' and it is most interesting to know that the oath which was taken by his pupils before they were allowed to practise medicine is still taken in much the same form by medical students to-day who are about to become doctors.

CHAPTER IV

Aristotle

We now come to the two greatest names among all the Greek Philosophers, Plato and his pupil Aristotle. Plato himself was a pupil of another, the famous Socrates, of whom you have probably heard; and Aristotle, in his turn, was tutor to Alexander the Great. So we have a chain of four great personalities linked together; and the interesting thing is that they are all quite different. From the point of view of science, Aristotle is far the most important of the four.

Plato.—Plato, who lived between the years 427 and 347 B.C., founded a very famous school in Athens known as the Academy. It stood in a pleasant grove with shady walks, and over the door was written the inscription: 'Let no one ignorant of Geometry enter here.' This would lead you to think that Plato must have been a true follower of Pythagoras, but this was not the case; for he thought that to apply geometry to practical purposes, such as making instruments, was degrading it. Geometry, he said, was a means of withdrawing the mind from material things and concentrating them on the abstract. Thinking, in this way, on geometrical figures he came to the conclusion that the circle was the most perfect curve in nature, and that therefore the paths of the various heavenly bodies must be in circles. Now, Plato was such a great man that his teachings were implicitly believed, not only by all the Greeks who lived after him but by all the people of western Europe for many hundreds of years.

So that, when a man named Kepler, who was a friend of Galileo, nearly two thousand years later, showed by observation and calculation that most of the planets did not travel in circles but ellipses, very few people, at the time, were disposed to believe him.

Plato was not really very much interested in the natural world about him. He was far more interested in Man and in the way in which he ought to behave; or, to use the proper word, he was interested in Ethics. His use for geometry was, therefore, to teach his students to think clearly and reason logically.

Aristotle.—To Plato's Academy, when he was eighteen years old, came an enthusiastic, energetic young man named Aristotle. Aristotle was born in Stagira in 384 B.C. and was the son of a physician. He had, therefore, been brought up amid circumstances which had created an interest in medicine and biology, and this persisted even when under such different influences as at the Academy. He worked so hard that he quickly became one of Plato's best pupils. He is said to have reduced the hours spent in sleep to a minimum. When he was reading in bed at night he placed beside him a brass basin, over which he held in his hand a leaden weight. When he was overcome with sleep, the weight dropped from his inert hand and the sound of its fall into the basin awakened him. It is not altogether surprising that a man of such persistent and untiring energy should have exercised such an influence over the thoughts of mankind for so many hundreds of years.

Aristotle stayed at the Academy until Plato died in 347 B.C. He then left Athens and shortly afterwards became tutor to the young Prince Alexander, son of King Philip of Macedonia. When Alexander became king

Aristotle returned to Athens and started a school of his own, which was called the Lyceum. At the entrance to the building was a covered portico or 'peripatos,' from which led a gravel walk between an avenue of trees. Here Aristotle used to walk up and down with his pupils, discussing various problems and teaching as he went. Because of this, his school became known as the Peripatetic school, and his followers were known as the Peripatetic philosophers.

It was at this famous school that, during the next twelve years, Aristotle gave himself up entirely to what he considered his 'life-work.' This, very briefly, was to write a catalogue or compendium of the knowledge of all natural phenomena. Up till then the various great men who had found out things and taught their knowledge to others had done so chiefly by word of mouth, and only fragments of their teachings had been preserved in writing. It is, of course, chiefly because of the fact that Aristotle wrote down so much that his teachings had so much influence for such a long time.

Aristotle's method of setting about things was this: First of all, he collected as many 'facts' as he could about every kind of subject he could think of—animals, fishes, plants; moving bodies; different kinds of matter; the phenomena of burning; the stars and heavenly bodies, and so on and so forth. Then he classified them into groups and under various heads; and finally he made theories as to why things happened as they did and were as he found them, reasoning always about things in the proper logical way which he had learned from Plato.

All this sounds very excellent, and yet Aristotle was one of the greatest stumbling-blocks in the way of later great scientists such as Galileo. How did this come to be so?

The explanation is this. Aristotle's reasoning was all right—he is still admitted to be one of the greatest exponents of logic—but in so many cases his 'facts' were wrong. He did not trouble enough to test his facts for himself, but either believed tales which were told him or assumed that things happened in a way in which they really did not. Perhaps the most famous example of a wrong fact is the one over which Galileo fought his famous battle with the professors of Pisa. Aristotle had taught that heavy bodies fall as many times faster than small bodies as they are heavier. Galileo, in front of all the professors, dropped a heavy weight and a light weight from the top of Pisa's leaning tower, and behold, they both reached the ground together! Now, although the professors did not even then really believe their own eyes, but still clung blindly to the teachings of Aristotle, yet I think we must allow that had Aristotle been there he would have at once given way to Galileo over the matter. The trouble with him was that he never thought of trying the experiment for himself. This applies to nearly all his teachings in the branch of Science which we now call Physics; and since it was in Physics that the great advance was first made in the sixteenth century, once this new Science had firmly won its place, Aristotle and his teachings became very much discredited.

His answers to the two great questions of the time were also very far from the truth, but because they were Aristotle's answers they were implicitly believed until finally disproved in modern times. As to the constitution of matter, Aristotle taught, like Pythagoras, that there were four elements—earth, air, fire, and water. Each element also was supposed to possess two out of four primary qualities—heat, cold, moisture, and dryness.

Thus earth was cold and dry; water was cold and moist; air was hot and moist; and fire was hot and dry.

Aristotle's idea of the universe was that the earth was fixed at the centre, and round it the moon, the sun, the planets, and the fixed stars revolved on separate spheres. So firmly did people believe that this view of the universe was the correct one that it almost became part of their religion, and hundreds of years later men who believed that Aristotle was wrong were persecuted and imprisoned for saying so, and one man was even burnt to death.

But there is one branch of science in which the work of Aristotle can win nothing but praise, that is in Biology. Before he became tutor to Alexander he spent two years on an island in the Mediterranean, watching and studying animal life, especially fish. The results of this careful study he wrote down in books which have come down to us, and later added observations made with the help of the students of the Lyceum. The books about animals are the only ones which have reached us, though probably he also wrote about plants. Biologists of to-day are still amazed at the wonderful accuracy with which Aristotle described the life and habits of the creatures he watched. He also studied, by dissection, the structure of their bodies, and by examining eggs at various stages of incubation was able to trace the development of the chick inside the egg.

In all Aristotle is said to have written between twenty and thirty books on various subjects, although quite likely much of what is said to have been written by him was really written by others.

Now let us consider just what of good service Aristotle did for Science, and what of bad. His greatest contribution was unquestionably that spirit of eager curiosity and

of inquiry which he brought to bear on every subject he investigated. That is the spirit which is to be found in every great scientist. His great dis-service was in stating so many things as facts, without first putting them to the test of experiment. Unfortunately his followers, especially those mediæval Christian monks who wove his teaching in with the teachings of their Church, thus giving them double authority, accepted blindly and unquestioningly his writings and ignored, or perhaps never even glimpsed, the man himself—the eager, curious seeker after truth. It was these men who were the true enemies of science.

Aristotle, then, built a great new stretch of the road of science. He made it wide and many travelled after him. The goal was clear in front of him, but he did not choose the right route, over the firm practical foundation of experiment. Thus, although the way looked straight and clear, the foundations of the road were faulty, and men coming after him sank and were lost in the mire of superstition and hearsay; or struck aside in search of will-o'-the-wisps that beckoned them astray.

CHAPTER V

Science in Alexandria

THE way now leaves Greece and again runs, for the next five hundred years, through Egypt. But the road-makers are still for the most part Greek by birth.

While Aristotle was teaching at the Lyceum in Athens, Alexander the Great was busy carrying out his conquest of the eastern peoples of Mesopotamia and Persia and of Egypt. In the last named, on the delta of the Nile, he founded the great city of Alexandria, which rapidly became a most important centre of trade and commerce. On the death of Alexander, his great empire was divided amongst his generals, and Egypt fell to Ptolemy, who was the wisest and ablest of them all. Under him—and, later, his son after him—Alexandria continued to flourish and became one of the most important cities of the world.

Ptolemy, besides being a great general, was also a learned man and liked to have always about him a group of philosophers and men of science. The rest of the empire, at that time, was in a very unsettled state, and so philosophers from all parts were only too glad to come to Alexandria and live peaceably under the patronage of Ptolemy.

After the death of Ptolemy his son determined to erect a building where all these philosophers could carry on their work and teach the young men that came in a continual stream to learn from them. Accordingly, the great Museum (or Home of the Muses) of Alexandria, was built,

and for the next seven hundred years this was the great centre of learning of all the civilised world.

The Museum was a very fine and beautiful building standing amid lovely gardens in which were shrubberies, flower-beds, fountains, statues, and alcoves. The building itself contained rooms of all sorts for study and recreation, but the most important of all was its great library. As many as possible of Aristotle's manuscripts were stored here and as much of Greek literature as could be procured. It is said that one of the rulers of Alexandria made a law that any notable man visiting the city must leave behind him a copy of any book he might have in his possession. So in one way and another books were collected until finally the great library is said to have contained seven hundred thousand volumes.

Alexandria thus took the place of Athens as the centre of learning and philosophy; and not only Greeks but, later on, the Romans came to Alexandria to be educated, just as, in the Middle Ages, from all over Europe young men went to the universities of Italy and to Paris; or, in our country, to Oxford and Cambridge.

At first the teaching was much the same as it had been at the Lyceum and the Academy, and Aristotle and Plato were names greatly revered by all. Gradually, however, a more practical side crept into the teaching. You will remember that the Greeks of Athens despised practical things and tried to make their teaching and thought as abstract as possible.

In Alexandria, however, there was constant contact with the natives of the country, the Egyptians and the Arabs. These, as you know, were intensely practical people, and undoubtedly influenced the Greeks living amongst them. So, instead of studying pure mathematics

and geometry alone, without relation to any definite, concrete matter, we find them studying mechanics—that is, mathematics applied to practical things such as the invention of machines.

Of the many hundreds of learned men who studied at Alexandria we can only mention *three* of the most outstanding.

Euclid.—Euclid was probably one of the first to come over to Egypt and settle in Alexandria. We know very little about the man himself, except that he lived somewhere about 300 B.C. and was possibly a pupil of Aristotle. His great book of Geometry, however, is known to all, though possibly not as bearing his name. Thirty or forty years ago the study of this subject was invariably known as 'Euclid'; and an English translation of the original work the only text-book used in this country. This book was really a collection of all the theorems in Geometry already produced by many Greeks before his time—Thales, Pythagoras, and many others—with some original ones of his own. It was the first time that they had all been collected together and arranged in order. No other book of Geometry was used to any extent for two thousand years.

Archimedes.—Probably you already know a good deal about Archimedes. He was born at Syracuse in Sicily in 287 B.C. He went to Alexandria to study (possibly under Euclid himself), and so, although most of his life was spent in Sicily, he rightly belongs to the 'Wise Men of Alexandria.' When he returned to Syracuse he devoted the rest of his life to study, experiment, and research. Notice that I said *experiment.* As a scientist he was far superior to Aristotle, although his work was far less well known until after the time of Galileo.

Archimedes was really the founder of the science of mechanics. He was an engineer and an inventor. He it was who first discovered the 'Law of the Lever,' and this he applied to the making of all sorts of practical contrivances. The most famous story of his bringing his ingenuity to bear upon a practical problem is, of course, that about Hiero and his crown.

Hiero was the King of Sicily when Archimedes lived there, and at one time he had a new crown made for him out of a certain lump of gold, which he supplied to the goldsmith. For some reason or other he suspected the goldsmith of stealing some of the gold and substituting silver in its place. The crown weighed the same as the original lump of gold, of course; and pure gold is not very different in appearance from gold mixed with a little silver; so that the King could not tell from looking at the crown whether his suspicions were right. He therefore sent for Archimedes, who had made a reputation already as being a very wise man, and asked him to try to find out whether the goldsmith really had stolen any gold.

Now Archimedes knew that silver, bulk for bulk, was lighter than gold; so that if some silver were mixed with the gold in the crown, the latter would be slightly more bulky than if it were made from pure gold. What puzzled Archimedes at first was how to find out just what was the volume of the crown, because it was, of course, not made in the shape of a nice regular cube, or other geometrical body, which he could measure up. He was probably thinking over this problem when, one day, he went to the public baths. The vessel in which he took his bath was quite full, so that when he got in some of the water overflowed. Suddenly it dawned upon him that just in proportion as his body was immersed so the water

overflowed; and if the water overflowing were collected then he could measure the volume of his body in the water. Here, then, was a way of finding the volume of the crown. In great excitement he jumped from the bath and rushed home without waiting to dress, crying, 'Heureka! Heureka!' 'I have found it! I have found it!'

He had next to find a lump of gold and a lump of silver, each of the same weight as the crown, and to discover the volume of each and of the crown by his new method. The crown he found to have a volume larger than the gold but smaller than the silver. So the goldsmith was guilty!

Yet, in spite of all the practical things he did, Archimedes' chief interest lay in abstruse mathematical problems, having no bearing on the everyday needs of life. He even went so far as to say that every kind of art is ignoble if connected with these needs. He was, indeed, a true Greek.

In 212 B.C. Syracuse was attacked by the Romans, and Archimedes devised war-machines and other contrivances with which to repel the besiegers. The enemy, however, entered and took the city. Archimedes was found absorbed in one of his mathematical problems, of which he had made a diagram on the sand. On the approach of some Roman soldiers he called out to them not to spoil his circle. This so angered one of the soldiers that he promptly drew his sword and killed Archimedes, not knowing who he was. The Roman general, however, was angry at the news, for he had heard of his reputation as a great man of learning. He caused Archimedes to be buried with honour, and had a mathematical diagram engraved on his tomb.

Ptolemy.—After Archimedes, there is no great name

worthy of mention for more than three hundred years, until we come to Ptolemy, the great astronomer and map-maker.

He was by birth an Egyptian, and studied at Alexandria. He is chiefly known because he wrote a very important book called the *Almagest*, which means the Great System; and this book was the standard work on Astronomy for many centuries. In this book he collected together the works of all the early Greeks and added very many observations of his own. He then set out to explain all these observations in the light of Aristotle's teaching of the nature of the universe. This was, you will remember, that the earth is a fixed and immovable sphere at the centre of the universe and that round it the other heavenly bodies travel in circles. The reasons that Ptolemy gave in support of this theory seemed very satisfactory at that time. The earth was said to be a sphere because, during an eclipse, it cast a circular shadow on the moon. This, of course, was perfectly correct. Next, the earth was said to be immovable, because, were it moving, everything on it, but not absolutely fixed to it, could not remain there, since heavy bodies travel more quickly than lighter ones. The lighter bodies on the earth would therefore get left behind. This, of course, is a very sensible argument, but unfortunately based on a wrong assumption about moving bodies, as we have seen. Lastly, it was said that the movements of the heavenly bodies must be perfect, and therefore must be in circles; for Plato had said that these were the perfect curves. Unfortunately, Ptolemy's observations showed him that the planets did *not* move in simple circles round the earth. He, however, very ingeniously invented a way in which he could make the

PLATE 1

Paracelsus

Archimedes

planets move in circles and still occupy their observed positions in the sky. He did this by supposing them to move in epicycles! That means that each planet kept moving in a circle round a definite point; but the point did not keep still but moved continuously in a circle round the earth. The diagram, fig. 3, should make this clear. Of course, it is not at all what the planets really

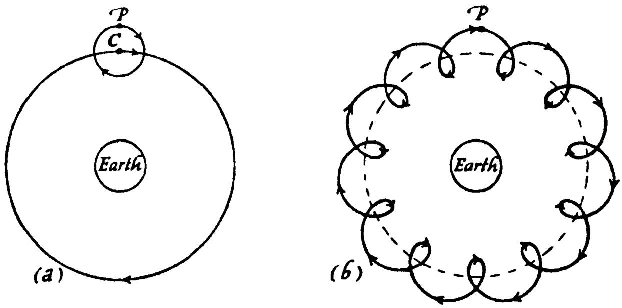


FIG. 3.—(*a*) the planet P moves in a circle round a point C which moves in a circle round the earth. (*b*) Shows the apparent path of the planet round the earth

do, but it saved Aristotle's reputation for quite a long time.

Besides being an astronomer, Ptolemy was also a great geographer. He wrote another book, which was used for many hundreds of years, and which contained maps of all the known parts of the world, including India, China, and even Norway. These maps all contained lines of latitude and longitude.

Apart from Archimedes, it cannot be claimed that the Greeks of Alexandria did much to extend the already existing road of Science. What they did was to keep clear and make known the road of Aristotle and others of the Golden Age of Athens. Archimedes, on the other

hand, struck out for himself, a clear straight road by way of experiment. He was a lone pioneer, however, and his way became lost in the centuries that followed. Nevertheless, it was his way that was followed by Galileo when once again the effort was made to get back on to the way with the firm foundation.

CHAPTER VI

Through the Dark Ages

So far we have only covered a comparatively short period of about five hundred years since the time of Thales, when Science, or the pursuit of knowledge for its own sake, might really be said to have begun. The great men we have talked about followed quickly, one after the other, and there were very many more whom we have not mentioned. Now we come to a long period of darkness and silence in the history of Science—when the path gets almost lost in a wilderness of superstition and quackery. This period lasts for about fifteen hundred years, during which no one man stands out as worthy to take his place beside the great 'seekers after truth' of the Greek era. Yet, if we probe the darkness and the silence of those long years we can follow the faint track whose beginning was carved out so boldly in Athens and Alexandria, winding tortuously through the wilderness and the gloom until at last it emerges suddenly into a burst of light and brilliance in the sixteenth century and becomes the great high road which leads directly to our own twentieth-century world of scientific wonders.

The conquest of Syracuse, in which Archimedes met his death, was one of the early stages in the conquest of the Greek empire by the Romans. Alexandria continued under the latter to be the centre of learning, but the first brilliance which was attained under the Ptolemies was never regained; and except for the Egyptian Ptolemy,

the astronomer and geographer in the second century, no science of any moment flourished there.

The Romans themselves had no love for science. They adopted the mathematics of the Greeks and applied it very successfully to engineering and architecture, and the fruits of this application are to be seen to-day in many Roman remains, especially in some of their very wonderful aqueducts for carrying water to their towns. But their engineers and scientists were always servants and very often slaves, and no honour was accorded to them. Small wonder, therefore, that science did not thrive.

The Roman Republic merged into the dissolute and decadent Roman Empire which, under Constantine the Great, became nominally Christian. In the struggle which had been waging between Christianity and Paganism the former now had the support of power and authority, and a time of terrible destruction of all things pagan began. It was at the command of one of the early Christian Emperors that a great part of the Museum Library at Alexandria was destroyed.

Even in Alexandria itself, though it was still nominally a centre of Greek learning, the old spirit had entirely disappeared. It was at this time that we find the first beginnings of Black Magic and all its attendant evils and superstitions which, in the centuries that followed, spread everywhere throughout Europe and Arabia. What we are chiefly concerned with here is the birth of Alchemy or the art of making gold.

The Egyptians, you will remember, were well skilled in metal work of all kinds. It was a common practice with them to colour, by their arts, many of the so-called baser metals so that they looked like gold. During the third century A.D. there arose a cult of people known as

the Alchemists, who claimed, with the help of certain Egyptian gods, to be able to turn these base metals into real gold. The word 'Alchemy' means really the Black Art. Whether this meant the hidden art because of its secret nature, or whether it meant the art of the black country because of the black mud surrounding the Nile after flooding, is not clear. The cult was probably originally limited to the Egyptian priesthood, but very soon certain Greeks of Alexandria were admitted. It was owing to these Greeks that Alchemy ever laid claim to be called a Science.

At this time the writings of Plato were revered above all others, and these early Greek alchemists sought and found, as they thought, justification in them for the claim that metals could be turned into gold. Plato, like Aristotle, had taught that matter was of four kinds—earth, water, air, and fire—but he had believed that it was possible to turn one kind into another.

We really do not know very much about these early alchemists, because we have very few of their writings; and those we have are so full of magic and superstition and secret signs and symbols that it is almost impossible to understand what they are about. One reason why we have so few of their writings is that one of the Roman Emperors became so frightened that a lot of gold might really be made which would not belong to him that he ordered all books which had anything to do with Alchemy to be destroyed. In this way still more of the library at Alexandria perished.

In the fourth century A.D. the Roman Empire was divided into two—an Eastern Empire with its centre at Byzantium or Constantinople, and a Western Empire still centred in Italy. Although the descent of the

Teutonic barbarians on Italy destroyed the Western Empire, the Eastern Empire continued to exist. As this included Alexandria and Greece itself, the old manuscripts, or at any rate copies of them, were kept more or less safely, chiefly in Byzantium. This city, however, became entirely cut off from the rest of Europe until the time of the crusades, and all trace of Greek culture disappeared for the time in Western Europe.

Meanwhile, however, another channel was being prepared through which these Greek writings should eventually reach Western Europe. We saw that Alexandria at one time was the centre of learning for the whole of the civilised world. Syrian and Hebrew scholars came there also to partake of the Greek store of wisdom. As a result of one of the many quarrels among the sections of the early Christian Church, a great number of these Syrians were expelled from the Eastern Empire where they had settled and become Christian, and were forced to return east to their own land. With them they took copies of the precious Greek manuscripts which they set about translating into their own language, Syriac. In this way the culture of Alexandria was preserved in this eastern land.

During the seventh century the foundations of the Arabian Empire of Islam were laid by Mohammed; and within a hundred years of his death the Arabs had conquered the whole of Persia, Asia Minor, the North-East of Africa, and were spreading into Spain. Although a warlike race, the Arabs had a very great respect for the learning of the Syrians whom they conquered. The latter were given posts as physicians, astrologers, and alchemists throughout the Empire. In the time of the great Caliphs, great centres of learning and culture were

established, where the Syrian manuscripts were translated into Arabic. Such centres were to be found at Basra, at Baghdad of Arabian Nights' fame, and at Cordova in Spain. Here, during the Middle Ages, came Europeans to study, and so the old learning of the Greeks, now interfused with later Arabic culture, returned once more to Europe.

Arabian Science.—It is probable that the Arabs added little new to the knowledge of the Alexandrian alchemists, but as our chief knowledge of the latter is from Arabian writings it is not easy to be sure on the matter. The pursuit of all the alchemists was, by this time, the search for the 'Philosopher's Stone,' that substance which should turn all metals into gold. In this search it was inevitable that a fairly extensive knowledge of common substances and their properties should have been gained and various methods of preparing them invented. All the common chemical processes, such as distillation, evaporation, crystallisation, etc., were known in those days, though the vessels used were not like our modern chemical apparatus of to-day. The only method of heating was on an open fire, and a great many of their vessels were made of fireclay and earthenware, although glass was used to a certain extent. These vessels were sealed or 'luted' with clay, for corks and rubber tubing were unknown.

The Arabs were amazingly clever workmen, and produced wonders in metal work of all sorts; in dyed fabrics; and in glass and pottery ware. There are many stories of the Moors in Spain, in which are to be found descriptions of the magnificence and splendour amid which they lived. Another very interesting thing we hear about them is that they were the first to introduce the use of

paper into Europe. This came to them from China by way of Central Asia and Arabia. When paper was in use the way was open for the invention of printing and the use of books.

The Arabs studied the science of light and were probably the first to make lenses—a very useful art, as Galileo found! They built observatories for studying the stars and constructed many astronomical instruments of types which are still in use to-day. In mathematics they added little to the geometry beloved of the Greeks; but they produced the system of Arabic numericals (1, 2, 3, 4, etc., instead of the Roman I, II, III, IV), which we use to-day. The invention of algebra is almost wholly Arabic; and the beginnings of trigonometry must also be attributed to this people. In medicine they made great advances.

While the Arabs were amassing and storing this immense amount of detailed practical knowledge, Western Europe was gradually settling down after the Dark Ages, and kingdoms roughly corresponding to our modern national divisions were growing up. The most important thing to notice is the growth of the power of the Popes at the head of the now universal Church of Europe. Most of these early Popes were very autocratic and very jealous of any influence in men's lives other than that of their own. Thus there came to be only one authority in Europe, the authority of the Church; and the word of the Pope, through his priests, was obeyed unquestioningly. The common man was allowed to have no intelligence or mind of his own; and any attempt at freedom of thought, either religious or otherwise, was stamped out with cruelty and intolerance.

Next we must turn to notice the growth of the monas-

teries and of the mediæval universities. Here the only learning sanctioned by the Pope flourished, and here gradually grew up that narrow and bigoted tradition with which Galileo was to clash so violently. The first monasteries were founded at the end of the fifth century, and the monastic movement spread rapidly during the seventh and eighth centuries. They were, of course, great centres of light and learning during those very turbulent times; and the growth of education in Europe, and the multiplication and storing of manuscripts, was due entirely to them. At first the Church had little literature of its own, and it was forced to depend on old Latin manuscripts of Roman writers. During the tenth and eleventh centuries Arabic translations of the old Greek manuscripts found their way into Europe and were translated into Latin—the language of the Church. These had been translated already into two different languages—Syriac and Arabian—and as no translations are perfect, and mistakes in copying easily made, it is not to be wondered at that these Latin translations were often very different from the original. The manuscripts contained chiefly the teachings of Plato, as interpreted by later writers, and were mainly concerned with Alchemy.

In the twelfth century the Crusades brought about the first contact between Eastern and Western Europe for many a long year. Palestine was reached by way of Byzantium, where some of the more educated Crusaders were attracted by the Greek manuscripts which they found there. It was in this way that many of the writings of Aristotle reached Europe and engaged the attention of a learned monk named Thomas Aquinas. He translated these manuscripts into Latin and made a very careful study of them. He came to the conclusion that the

teachings of that famous old Greek were fully in accordance with the Roman Catholic doctrine. So Aristotle received papal sanction. His writings were studied and copied with such enthusiasm in all the monasteries and universities that, within a comparatively short period, to disagree with his teachings was heresy in the eyes of the Church and punishable by fire.

During the centuries that followed, the works of Aristotle formed the central study at all the universities throughout Europe, and that part of Aristotle's teachings that these mediæval professors and students learnt better than anything else was to argue in a strictly logical manner. To them, a learned argument came to be the most convincing of all things—far more convincing than anything they saw or heard for themselves; and in the great battle fought in the sixteenth century this was the weapon which the opponents of the new science brought with such confidence to the fray.

Alchemy.—It is hardly surprising that, with the minds of men turned so firmly towards the past, little advance was made in science during those years. After all, Aristotle had written an amazing amount about the natural world, and that amply sufficed for these old scholars. The chief science, so called, of that time was the ancient art of Alchemy which came to Europe from the Arabs. Attached to the court of almost every noble was an alchemist, who, as a rule, practised also astrology and magic. He advised his lord as to auspicious occasions on which to carry out his activities. The idea of having untold wealth at his command naturally inflamed the imagination of each nobleman. Many a fraudulent experiment was staged to convince him that the secret had been gained and so assure continued favour for the alchemist.

Nevertheless, the majority of the really intelligent men of the day honestly believed that transmutation into gold was a real possibility if only the philosopher's stone could be made. Their justification for the belief was to be found in the views which they held concerning the nature of matter, which views they derived from Aristotle. Let us remind ourselves what they were:

> Anything which occupied space consisted of matter of some sort.
>
> There were four different kinds of matter, called the elements; these were earth, water, air, and fire.
>
> Solids consisted chiefly of the element earth, but often contained smaller amounts of the other elements which could generally be driven off by heat.
>
> Liquids consisted chiefly of the element water.

By sufficiently altering the properties of a substance—as, for example, its appearance and texture—it was possible to turn it into something else. This is what Aristotle taught.

In addition, the alchemists of the Middle Ages held certain ideas as to how the metals came to be formed. These had come down to them from the Arabs. From the four elements present in the earth, the first compound substances to be formed were mercury and sulphur. These two mixed together beneath the surface of the earth and under the influence of great heat and during the lapse of a considerable period of time formed the metals. If the conditions were quite perfect and the heavenly bodies in favourable positions with reference to one another, then gold, the perfect metal, was formed. If not quite enough time was taken over the process, then not gold but silver was the product; while if any, or all, of the

other conditions were wrong, then either copper, tin, iron, or lead were formed instead.

According to these ideas, therefore, the base metals were thought to be just impure gold, or gold gone wrong in the making; and so it should not be so difficult to alter those qualities which were wrong, such as colour, hardness, etc., and get gold in the end. Needless to say, the mediæval alchemists were no more successful than their predecessors; but all the time they were improving their methods of working; and from time to time new substances were discovered. Many of these are the common reagents of our chemical laboratories to-day, although they were then called by quite other names. For instance, what we call nitric acid they called aqua fortis (strong water), because it would dissolve so many metals; while aqua regia, which is a mixture of nitric and hydrochloric acids, was so called because it alone would dissolve that king of metals, gold. They also discovered what they called spirits of salts (hydrochloric acid), spirits of hartshorn (ammonia), and many others. Nevertheless, in spite of such discoveries, no real advance was made in understanding the nature of the materials they used and the reason for their various reactions upon each other. It was not until the seventeenth century that chemistry as an ordered science came into being.

Paracelsus (1493–1541).—Before that, however, the search for new substances was widened considerably owing to a man commonly known as Paracelsus (his real name was Theophrastus Bombastus von Hohenheim!). He was a Swiss physician who lived in the sixteenth century—very much later than the times we have been talking about, but still before the birth of modern chemistry. He taught that a great deal of talent and energy was being

wasted in this search for the philosopher's stone. These, he said, should be turned instead to the study of substances with a view to their use as medicines, and especially should search be made for that substance, the Elixir of Life, which should prolong life indefinitely.

Paracelsus fell out very badly with the rest of his profession because he publicly burnt all his books written by Galen and Avicenna, the two great authorities on medicine; and said that, henceforth, he would rely only on his own powers of observation and his experience gained by the use of his medicines.

He had some very curious ideas as to how our bodies function, but these do not concern us here. He also produced a new theory as to the composition of matter, substituting for Aristotle's four elements the three 'principles' of sulphur, mercury, and salt. The part of a substance which would burn contained the principle of sulphur; that which would volatilise or turn into vapour when heated contained the principle of mercury; while the solid which remained when all the sulphur and mercury had been driven off contained the salt.

By this time, you see, the yoke of Aristotle had been lifted somewhat and new ideas were being produced. It cannot be said, however, that the new theory of Paracelsus was a great improvement. What is to his credit, however, is the impetus which he gave to the search for new chemical substances.

This, then, is the story of Alchemy up to the middle of the seventeenth century, and to make it complete we have really gone too far ahead in time. Now we must go back again to the thirteenth century and hear about one man who realised what shackles bound men to the past and had a vision of what true science ought to be.

Roger Bacon (1214–1294).—This man was Roger Bacon, an Englishman. Because of his new way of looking at things he has been called 'the Herald of the Dawn.' Like all the educated men of that time, he was a monk; but he was a very unorthodox monk and frequently in hot water because of his outspokenness. He claimed that the true way to acquire knowledge was by experiment and not by argument; and that authority (for example, what Aristotle said) carried no weight if experiment said otherwise. He lived up to his teaching by carrying out a great many experiments; and he made a number of new and valuable discoveries, more especially in connection with Light. He was an alchemist as well, and believed in the possibility of transmutation. He wrote down the results of his experiments, together with his ideas on how science should be studied, in three books which he called *Opus Maius* and *Opus Minus* and *Opus Tertium*. As you might expect, these books were not at all popular with the authorities, and he was put into prison for writing them. He was kept there for fourteen years, and was only released, to die almost at once, in his eightieth year.

Leonardo da Vinci (1452–1519).—After Roger Bacon came another period of three hundred years when no name stands out as worthy of mention, except that of Leonardo da Vinci. This great Italian lived about two hundred years after Roger Bacon, and a hundred years before Galileo. Leonardo da Vinci is, perhaps, best known as a painter; he painted the famous picture of the 'Last Supper' and also the portrait known as 'Mona Lisa,' both of which are considered to be amongst the world's greatest pictures. Only comparatively recently has it been realised that his genius was by no means limited to painting or any form of art. He had a passion

for knowing the truth about things, and his notebooks are full of drawings and notes on every conceivable subject, from designs for flying-machines to the habits of poisonous spiders. He loved mathematics, and by its aid designed a great variety of machines, many of which were used by his patron, the Duke of Milan. He scorned the alchemists in their search after gold, and fully realised the impossibility of transmutation. His notebooks show that he discovered many things which did not become generally known until their rediscovery by others much later. One writer about Leonardo has said that if Galileo is called the 'Father of Experimental Science,' then Leonardo da Vinci might be called its grandfather!

Certainly both Roger Bacon and Leonardo da Vinci broke away from the darkness and reached the light—but the rest of their fellows were not ready to follow them. So no permanent way was yet made.

CHAPTER VII

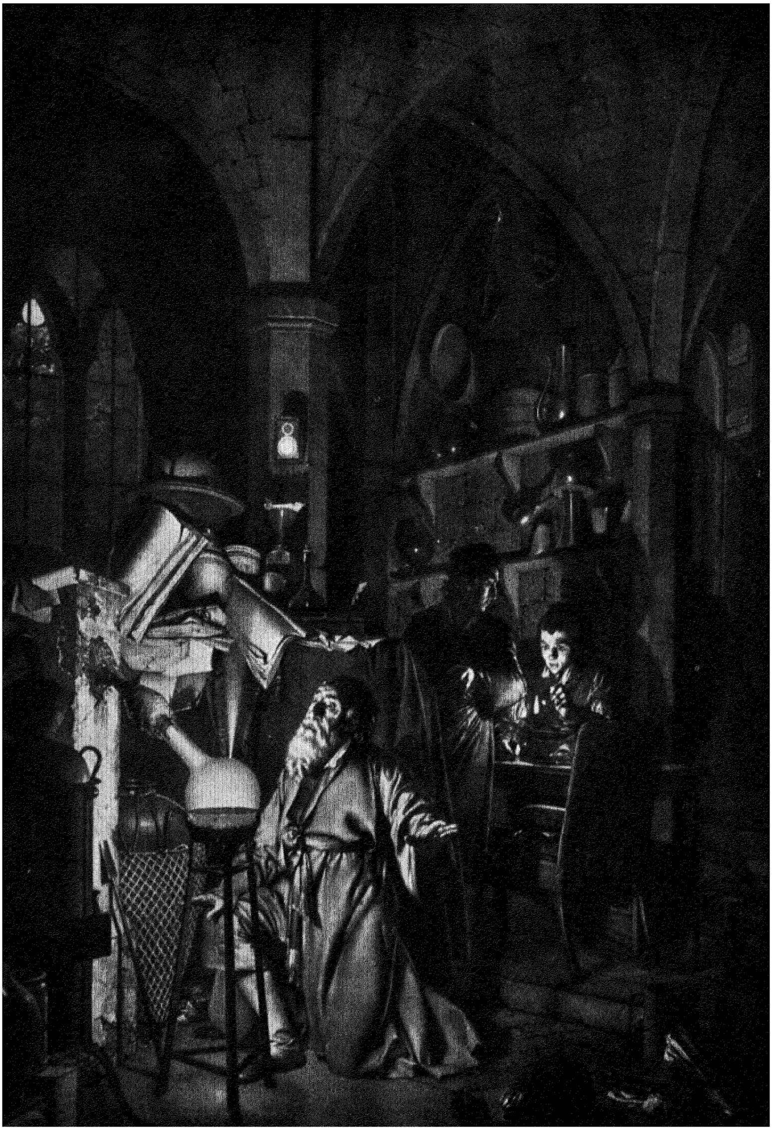
The Dawn of a New Age

THE man who actually ushered in the new age of science was *Nicholas Copernicus*. He was born in 1473 at Thorn, in Poland, on the River Vistula. His great contribution to Science was his conclusion, arrived at after a lifetime of careful observation of the heavens, that it was the earth which moved round the sun and not the sun round the earth, as all the world then believed because of the teachings of Aristotle and Ptolemy.

Copernicus first went to the University of Cracow with the object of becoming a doctor. He soon found, however, that he was far more interested in mathematics and astronomy than in medicine. After qualifying to be a doctor he devoted himself to the study of these two other subjects, and before very long he became Professor of Mathematics at Rome. He did not stay long at Rome, however, but, being appointed a canon in the cathedral of Frauenburg, he returned to his own country. Here it was that he spent the rest of his life and carried out that wonderfully exact series of observations which finally led him to his famous decision as to the true state of affairs among the heavenly bodies.

Let us see how he carried out these observations. Remember that the telescope was not yet invented, nor many of the other great instruments of our modern observatories. First we must understand just what it was that he had to do. Imagine a great circle passing through the North and South Poles and the point

PLATE II



An Alchemist at Work

PLATE III

Leonardo da Vinci

Copernicus

immediately overhead (the zenith). This circle is called the meridian. The sun crosses the plane of this circle every day at noon, and at some time during the twenty-four hours every star crosses it. The time at which each star does this is a very important determination in astronomy. To carry out these determinations, he

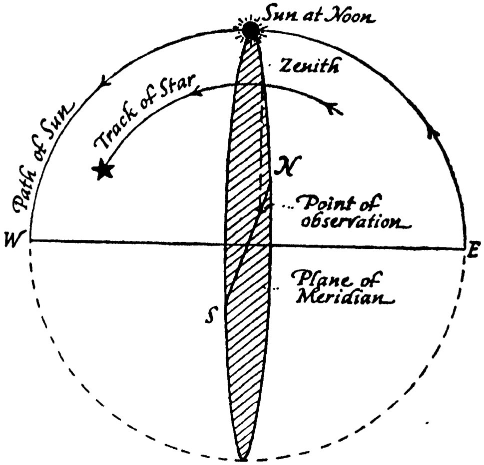


FIG. 4.—The meridian. The shaded area indicates the plane of the meridian, at right angles to the plane of the paper

arranged slits in the walls of his house so that he could note the 'transit' of the stars across the meridian. He also made himself an instrument called a quadrant, by which he could measure the altitude of each star as it passed.

Copernicus studied especially the movements of the planets, and it was this study which led him to his famous conclusion. Now it is most important that you should not think that it was quite a new idea to Copernicus that the earth should move and the sun stay still. He was a very well-educated man and definitely tried to read as

many as he could of the writings of the ancient Greeks about their ideas of the universe. Thus he knew very well that although Aristotle had taught that the earth was still, Pythagoras had said that it, and the planets, moved round a central fire; while a later astronomer, Aristarchus, had actually taught that the sun was the centre round which the earth and the planets moved.

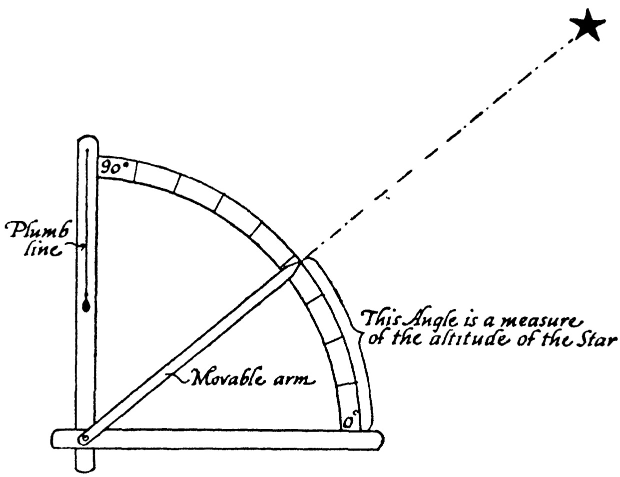


FIG. 5.—A simple quadrant

What Copernicus did, therefore, was to show that the motions of the planets, as he had observed them, were in agreement with the theory of Aristarchus rather than with that of Aristotle and Ptolemy.

Copernicus was a very modest and retiring man and was not at all anxious to make his views known, but his friends finally persuaded him to publish them. This he did in the famous book called *De Revolutionibus Orbium Cœlestium*. This, however, was not until he was an old man, and before it was published he was smitten with a paralytic stroke, and it was only a few hours before his

death in 1543 that the first copy of the book was put into his hands.

Now, although Copernicus was a canon of the Church he realised that his book would be extremely unpopular. Nevertheless he dedicated the book to the Pope, and expressed his conviction that the ideas which it contained were not contrary to the truest and best teachings of his Church.

At first the Pope was immensely pleased by the dedication; but when once the contents of the book were fully understood, it called forth quantities of abuse, and any man proclaiming himself to be a convert to the Copernican view suffered great disrepute. Indeed, a certain man named Giordano Bruno was imprisoned for six years and finally burnt at the stake.

Before we come to Galileo, who was the greatest of all the supporters of this theory, there are two men whose joint work was tremendously important to the progress of the new astronomy. The first of these, Tycho Brahé, was never a convert to the Copernican theory, while the second, Kepler, was its keen supporter from the first.

Tycho Brahé.—Tycho Brahé was a Dane of very good birth. At that time it was not at all usual for well-born people to receive a good education, but luckily Tycho Brahé had an uncle who was himself well educated, and he adopted this nephew and sent him to the University at Copenhagen. He was really meant to study law, but the occurrence of an eclipse which had been predicted so fired his interest in astronomy that he decided to devote his life to its study.

From the first, his real interest lay in making observations of the heavenly bodies rather than in inventing theories to account for their movements. This was just

as well, as the one theory he did put forward was not at all a brilliant one. On the whole, he was a fairly steady supporter of Ptolemy's system all his life.

Tycho Brahé was at once struck with the inaccuracy of all the observations of the stars which had been made hitherto, even those of Copernicus. He therefore set about making much larger and more elaborate instruments, and by their aid was able to carry out observations far exceeding in accuracy any which had previously been made. This accuracy was due not only to the superiority of his instruments but also to the skill and care of Tycho Brahé himself.

The King of Denmark was greatly impressed by his ability, and seemed to have realised that every help and encouragement should be given to a man of his eminence. He therefore gave him an island and £20,000 with which to build an observatory. This observatory, which was called Uranienburg (the castle of the heavens), was a wonderful affair when it was built. It was fitted with laboratories and workshops, and in the actual observatories with the most splendid instruments that Tycho Brahé had so far made. Here for the next twenty years he gradually accumulated the most complete and accurate set of observations on the heavenly bodies that had ever existed. He won great renown as a man of Science, and was visited by eminent personages from all over Europe.

Unfortunately, when his patron the King of Denmark died, he lost favour with the new king and had to abandon his wonderful castle. After two years of wandering in Europe he was invited by the Emperor of Bohemia, Rudolph II, to settle in Prague, and was given a castle, to which he was able to bring his instruments. Once more students flocked to him, and an important piece

of work was begun which he called the Rudolphine Tables —astronomical tables intended for the use of navigators. But the anxiety and privations of the last years had so told on Tycho Brahé that he soon fell ill and died in 1601, committing to Kepler, on his death-bed, the work of completing the Rudolphine Tables.

Kepler.—Johann Kepler was born in very different circumstances from Tycho Brahé. His mother was low-born and bad tempered, and his father continually in money troubles. When four years old Kepler suffered from smallpox, which left him with impaired eyesight and an unsteady hand. At ten years old he was taken from school and served as a pot-boy in a tavern which his father was keeping at the time. Later, however, he was able to attend a monastic school and finally managed to get to the University of Tübingen. Here the professor of mathematics soon detected Kepler's genius and at once introduced him to the doctrine of Copernicus to which he himself was an acknowledged convert. Kepler became a powerful defender of this doctrine and soon established a considerable reputation. At twenty-three years of age he was offered a professorship in Astronomy at the University of Graz, which he accepted for the time being, but determined to look out for something better, as the salary was not at all good and he was tired of continual poverty.

The question which most of all interested Kepler was whether there was a definite scheme governing the movement of the planets. There were still only six planets known—Mercury, Venus, the Earth, Mars, Jupiter, and Saturn; and of course it was only people who believed in the Copernican theory who thought of the Earth as a planet. Kepler also knew that Saturn was the farthest

from the sun and moved most slowly, and that Mercury was nearest and moved the fastest. What he wanted to find out was why there were six planets—no more and no less; what was the connection between the orbit or path in which they travelled round the sun, the time they took to travel round it and their distance from the sun? It was to the answering of these questions that he devoted his whole life, and success crowned his efforts finally in a very brilliant fashion.

While he was at Graz he evolved his first theory concerning the planets. This was very elaborate, rather fantastical, and proved to be wrong, but I mention it here because it was probably this theory which brought him into touch with Tycho Brahé. The latter had by this time been compelled to leave Uranienburg and was then at Prague. Kepler wrote to ask if he might visit him in order to find out whether Tycho's observations on the planets would support his own theory about them. Tycho at once told him to come and share his work with him. Now Kepler, owing to his weak sight and general ill-health, was quite unfitted for such work, which meant much outdoor work at night, good eyesight, and a steady hand. He was therefore rather reluctant to accept the offer, but finally did so, and was before long appointed by the Emperor as Tycho's mathematical assistant. He quickly found that his first theory must be abandoned as it did not fit the facts, and set to work again on the problem. In the meantime, however, Tycho Brahé died and entrusted to Kepler the completion of his Rudolphine Tables. The Emperor had been involved in wars and other political complications, and Kepler found it almost impossible to get the money to go on with the work. Eventually, however, after long delay, they were com-

pleted, but money was still required to publish them. For four years he tried to get the money from the Emperor, but at last he was compelled to raise the money for it himself. All his life he was desperately poor, as he never could get his salary paid. Where he got the money from to publish the tables is not known, but somehow or other he managed to keep his promise to his friend and benefactor. The publication of these tables was a very important event in the history of astronomy, as they were the first really accurate tables which navigators ever possessed.

All this time he had been going on with his own work, and success had at last crowned his efforts, atoning in great measure for the misery and privation he had to endure. You will remember that he was trying to find out about the connection between the orbits in which the planets travelled and the time in which they described those orbits. At first he, like everyone else, assumed that they must travel in circles round the sun at the centre. This was, I suppose, really because Plato and Aristotle had both said that the circle, being the perfect curve, must be the path in which the heavenly bodies moved. Ptolemy, it will be remembered, found that his observations of the planets showed that they did not travel in simple circles round the earth; and so he invented epicycles. Kepler tried all sorts of ideas, but had no success until he gave up trying to use circles at all. It is only possible here to state, quite simply, what he eventually discovered. His methods were entirely mathematical and we cannot follow him into that region. This is what he found out:

(1) Each planet moves in an ellipse round the sun, which is at one focus. (Look at the diagram to see what the focus is.)

(2) If a straight line were drawn between the sun and the planet, then that line would sweep over equal areas in equal times. (Again look at the diagram.)

(3) He also found out that there was a definite mathematical connection between the time taken by any planet to revolve round the sun, and its average distance from the sun.

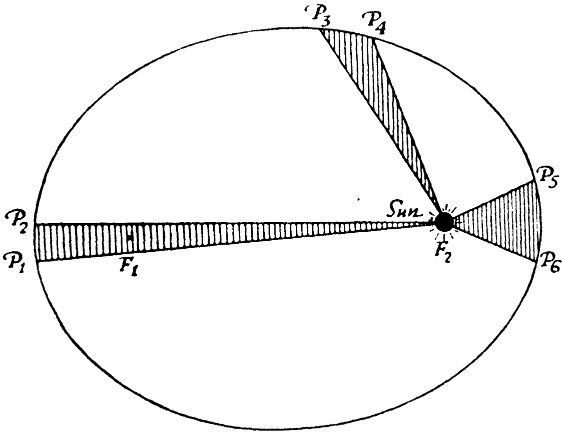


FIG. 6.—F_1 and F_2 are the foci of the ellipse. The sun is at the focus F_2. The planet moves from P_1 to P_2, P_3 to P_4, and P_5 to P_6 in the same time if the shaded areas are equal

The beauty about Kepler's discoveries is that there was no doubt about their being true. They were found entirely from Tycho Brahé's observations. So you see the two men were absolutely necessary to each other. Kepler could not possibly have discovered his laws without Tycho Brahé's observations, and these observations would have been of far less value if they had not been so brilliantly interpreted by Kepler. Kepler published his results in a book in which he set forth plainly the Copernican theory. It was at once suppressed and placed

on the list of books prohibited by the Pope side by side with the work of Copernicus himself. His work at the time was very little appreciated, and when he died in 1630 it was as a result of exhaustion after a fruitless journey to Prague to try to get some of the money due to him from the Emperor. Everything was against him all through his life, and yet his achievements were great. He produced the beginnings of law and order out of chaos and paved the way for the genius of Newton.

CHAPTER VIII

Galileo

THE real hero, and the leader, of the great revolution in Science was Galileo Galilei, who was born in Florence, in Italy, in 1564. He it was who once and for all turned away from the old road of Aristotle and set his face towards the firm ground of practical experiment.

When he was quite a boy he loved to make things with his hands and to draw and paint. He believed in finding things out for himself, and used to argue with his teacher as to whether Plato and Aristotle were really right in what they said and whether they had tried things for themselves.

When eighteen years old he made his first discovery. He was in the cathedral of Pisa at his prayers one afternoon when a choir boy went his round to light the lamps. From the great dome of the building there was suspended on a great chain a very beautiful lamp. The boy pulled this lamp towards him to light it, and then let it swing back. Galileo stayed watching the lamp swing, casting its weird shadows through the great building. Gradually the swing died down and the lamp moved more and more slowly. As he watched, it seemed to Galileo that although the distance over which the lamp moved was so much shorter yet it took just about the same time to cover it as did the first longest swing of all. But a rough guess was not enough for Galileo. He had no watch, but instead he put his fingers to his pulse and counted. He was right; every swing—even the last little one before the lamp was still—

took just the same time. Experiments of his own showed him that the length of time a pendulum takes to swing depends, not on the distance through which it swings, but only on the length of the chain or string. The longer the string, the slower is the rate of swing. Galileo then made a little instrument, consisting of a weight on a thread, for doctors to use to measure a sick person's pulse. The thread could be adjusted so that the pendulum swung in time with the pulse. A long string would mean a slow pulse and a short string a quick one. Later, of course, Galileo's discovery was made use of in making clocks, such as grandfather clocks and many of the big clocks on buildings.

Galileo's father badly wanted him to be a doctor, but Galileo had set his heart on learning mathematics. Now at that time it was a much more paying proposition to be a doctor than to teach mathematics, and his father warned Galileo that if he persisted he would be very poor. He, however, cared nothing for that, and at twenty-six years of age he was made Professor of Mathematics at Pisa.

From the very first he was a nuisance to the other professors, because he would argue about things instead of quietly accepting what Aristotle or Plato had had to say on the matter. I have already described how he got them all together outside the leaning tower of Pisa, and, climbing the tower, dropped his two weights, one heavy one light, so that all could see them reach the ground together, thus proving Aristotle wrong. This incident made him very much disliked, and from then on he made many enemies, who were to do him much harm in later years.

He soon had to leave Pisa, and from there he went to the University of Padua as Professor of Mathematics, where he remained for the next eighteen years, teaching and also

experimenting on his own. At this time the new theory of Copernicus was being very greatly discussed, and in 1600 Bruno was burnt to death at Rome. It is not surprising to hear that Galileo was a firm believer in this new theory, and in fact became its chief defender.

In 1609, Galileo heard of a wonderful instrument made by a Dutch spectacle-maker. This consisted of two lenses so put together that when distant objects were viewed through them they appeared much larger and nearer than when viewed with the naked eye. When Galileo heard about this he realised what a valuable possession such a contrivance would be. He at once set to work to try to make one. He did not then know very much about lenses, but his ingenuity finally triumphed and he succeeded in making his first telescope. One can imagine with what excitement he began to use his new possession, and it was not long before he turned it away from the earth to the heavenly bodies. At once new worlds were opened to him. He found that there were mountains on the moon, spots on the sun, rings round the planet Saturn, and no fewer than four moons or satellites revolving round Jupiter.

These discoveries also caused much excitement amongst other people. Here is a description of its effect on the people of Venice, which Galileo wrote himself. 'As the news had reached Venice that I had made such an instrument, six days ago I was summoned before their Highnesses, the Signoria, and exhibited it to them, to the astonishment of the whole senate. Many of the nobles and senators, although of a great age, mounted more than once to the top of the highest church tower in Venice, in order to see sails and shipping that were so far off that it was two hours before they were seen, without my spy-

glass, steering full sail into the harbour; for the effect of my instrument is such that it makes an object fifty miles off appear as large as if it were only five!'

Galileo gave a spyglass—possibly the original one—to the Doge, or Grand-Duke, of Venice. There is still at Florence one of the telescopes which Galileo made, though whether it is this one I do not know. (See Plate V.)

His discoveries about the heavenly bodies, however, were not at all favourably received by the followers of Aristotle, who produced all sorts of learned arguments and quotations to show that Galileo was wrong. Most of them refused utterly to look through the telescope. I will quote just one bit of their reply to Galileo about the moons which he claimed to have seen revolving round Jupiter. 'These satellites of Jupiter are invisible to the naked eye, and therefore can exercise no influence on the earth, and therefore would be useless, and therefore do not exist.' To us this may not seem at all a sensible argument, but we live a great deal further along the road.

There is not time here to make it clear to you how all these discoveries of Galileo lent a great deal of support to the Copernican view of the universe, as opposed to that of Aristotle. You will, however, see at once that, with a telescope as an aid to vision, it was possible to find out a great deal more about what was going on in the heavens than it had been before. Galileo did not of course make all his discoveries at once with the first telescope. For the next few years he was hard at work continually improving on this first instrument. He taught many students how to make telescopes, and continually had them at work preparing new and better ones. In this way the use of the telescope gradually spread through Europe, and we find many more men at work studying

the heavens. Gradually with his improved instruments Galileo found out more and more, and was absolutely convinced that the old monk, Copernicus, had been right in his theory.

He was not at Padua all this time. Although the senators of Venice, who had appointed him to the professorship, were very pleased with him after his invention, and gave him a much bigger salary, quite soon afterwards he left Padua and went to live at Florence as Mathematician and Philosopher to the Grand Duke of Tuscany. This gave him much more time for his own work in astronomy, as now there were no daily lectures to be given. There was also, however, a less fortunate side to this move. Unlike Venice, which was a free republic, Tuscany was very much under the influence of Rome and the Pope. His old enemies, the Aristotelian professors, got to work and tried to stir up Rome against him, because of all the heretical views he was teaching about the heavens. Soon he was sent for to Rome and asked to explain his views to the Pope and the College of Cardinals. He was very nearly as good at argument as the professors themselves, but he had not the weight of authority behind him. At first the Pope was impressed and inclined to be well disposed towards him, but in the end his enemies won. Galileo was told that if he did not cease to teach his 'false, impious, and heretical opinions' he would be imprisoned and tortured. Reluctantly he gave his promise and was allowed to return to Florence.

For the next seven or eight years, Galileo was very careful of what he said, although he went on all the time with his researches. Then the Pope died, and Galileo managed to get into the good graces of the new Pope. This led him to think that perhaps now he could venture to put forward

his true opinions once more. He therefore began to write a book in which he set forth very clearly the Copernican system and the evidence in favour of it. He was very tactful in the way in which he did this. To begin with, he wrote it in the form of conversations between two men, one of whom upheld Aristotle's theory and the other that of Copernicus. Now this was a method of writing a book often followed by the ancient Greeks—especially by Plato. Secondly, he tried to be very fair to Aristotle in the conversations, although of course the latter was made very obviously to get the worst of the argument. When the book was published, it was read eagerly by everyone; but Galileo's enemies were roused at once and easily turned the Pope against him as well. The book was banned and Galileo ordered to come to Rome at once. It was now more than twenty years since he had invented the telescope, and he was becoming an old man. At Rome he was subjected to the famous Inquisition. He held out for a while, but finally, old and broken, he gave in and recanted, declaring that he acknowledged his new doctrine to be in opposition to the teachings of the Holy Scriptures, and swearing never more to teach it in any form whatsoever.

Copies of this recantation of Galileo's were sent to all towns throughout Europe and read publicly from every pulpit. The anxiety of the trial and the final disgrace had so affected the health of his favourite daughter that soon afterwards she died, and Galileo was thus left with this added grief and loneliness to bear. He was not kept a close prisoner for more than a few days, but was only allowed to return to his home outside Florence on condition that he remained there and never went outside it. Here he spent the remainder of his days, but not in

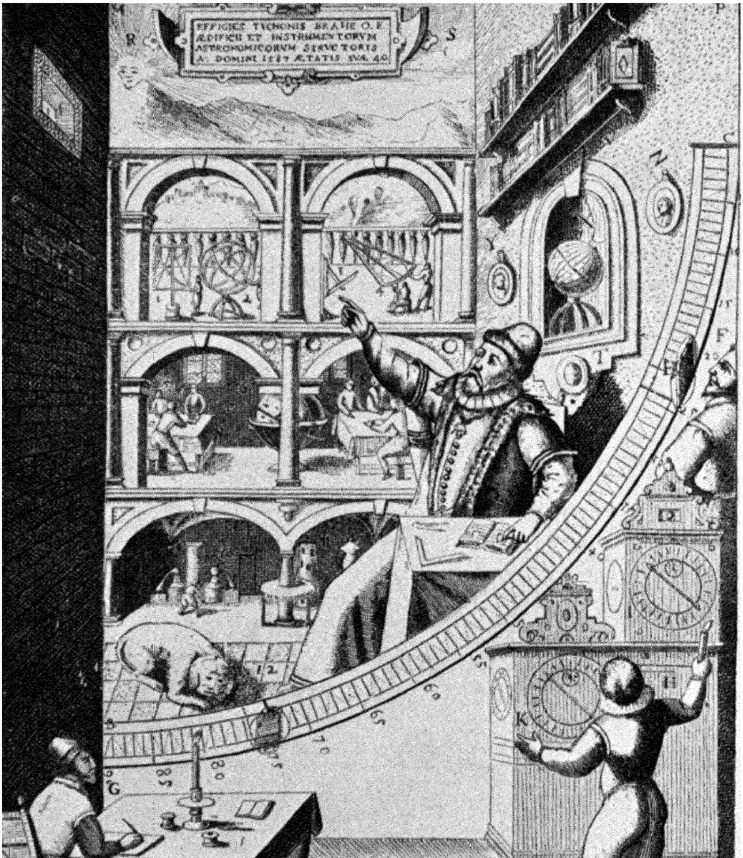
idleness. He now turned his attention to a subject which had greatly interested him before the invention of his telescope led him to the study of astronomy. This was an investigation of the laws which govern bodies in motion. Again I am not going into details as to what he really discovered here. It was very important and very valuable and laid the foundation of the work which was to be completed by his brilliant successor Isaac Newton. I shall say more about it when I come to him.

During these years a further misfortune befell him, for he became blind. He had, however, with him one or two devoted pupils who acted as secretaries to him and wrote his notes. One of them was Torricelli, the inventor of the barometer.

After a while, Galileo was not kept so closely secluded, and people were allowed to visit him. From all parts of Europe eminent people visited this now famous old man, amongst them the poet Milton, from our country. Galileo was failing in health, however, and in 1642 he died, at the age of seventy-eight years. Although honoured by many, he was still in disgrace with the authorities, who permitted no public funeral nor allowed a monument to be erected over his grave. They were, of course, powerless to stop the spread of the new doctrine, and by their very persecution roused the interest of all the educated people in Europe, so that Galileo soon earned the fame he deserved.

Now how was it that Galileo succeeded where Roger Bacon and da Vinci failed; that is, in definitely opening up the new and straight road of real scientific progress? It was probably more to do with the times in which they lived than in the men themselves, although Leonardo certainly had not the fighting personality of Galileo.

PLATE IV



Tycho Brahé in his Observatory

Note the use of the quadrant and the slit (top left-hand corner) to measure the altitude of a star. This gave a much more accurate measurement than any previously obtained by similar methods

Bacon, however, appears to have been of much the same calibre, and was as firm a believer in the value of experiment as Galileo. He, however, lived before the time of the Renaissance and of the Protestant Reformation. Men were not ready to break away from the old authority into new paths, and he therefore travelled a lonely journey and none sought to follow him. In Galileo's time, however, everywhere the Renaissance had done its work. Men were ready for new ideas and only the Church clung firmly to the old ways of thought. In many parts of Europe the Church had lost its hold and Protestantism and freedom of thought reigned instead. It was only because Galileo lived so close to Rome and in a state still within the jurisdiction of the Pope that he suffered so much from persecution. Thus, while he still lived, he was already gaining converts to the new view of Science, and at his death there were a number of real scientists in various parts of Europe already engaged in carrying on the road. As we shall see, the making of the road was soon not to be the work of any one man alone, but of an ever-increasing army.

CHAPTER IX

Newton, the Master Builder

FINALLY we come to the greatest of all the road-builders, Isaac Newton. He strengthened, broadened, and made clear the path already made by Copernicus, Galileo, and Kepler, and, in addition, laid a broad, new stretch of his own. Thus the narrow road, hitherto trod by only a few of the boldest and most far-seeing, was now transformed into a great thoroughfare, along which all who took the trouble to learn the rules of the road might follow. After Newton came a whole army of workers who now divided the road into separate 'tracks,' running side by side. The workers on each of these occupied themselves with just one branch of Science. For scientific knowledge had grown so great that it became necessary to divide it into various branches. These were Astronomy, Mathematics, Physics, Medicine, Chemistry; and later, Biology, Geology, and Physiology. There are many great names connected with all these great branches of Science, but almost all of them owe something to Newton, who set forth so clearly the 'rules of the road' and invented new and useful tools with which to work.

In the year that Galileo died, 1642, Isaac Newton was born in a small village in Lincolnshire. His father, who died before he was born, owned a small manor, which his son, therefore, inherited from him. At the local school at Grantham, Isaac at first by no means distinguished himself, being far more interested in making toy models and mechanical contrivances than in the

study of books. However, this state of affairs was altered in rather an amusing fashion. One day he had a fight with a boy, bigger and older than himself; and succeeded in thrashing him. His self-esteem thereby rose exceedingly, and, spurred to further efforts, he turned his attention to his school work, with such success that he was soon top of the school.

When he was fifteen his mother felt it was time to train him to manage his own land, and he therefore left school. He soon found, however, that he had no liking for farm work, and invented many ways of dodging it. Whenever possible he retired to an attic, or to a secluded seat beneath a hedge, and devoted himself to his books or to the invention of some new contrivance. His mother, despairing of her son as a farmer, sent for her brother to advise her. Isaac was found sitting under a hedge with a book on mathematics, when he should have been attending to his work on the farm. His uncle wisely advised letting him give up the idea of farming and go to Cambridge.

A new and marvellous world now opened out for Newton. His education at the local school had consisted entirely of Classics; of mathematics and science he knew nothing except the little he had picked up on his own. He read everything he could lay hands on and soon made good his past deficiencies. After taking his degree he helped the Professor of Mathematics at Cambridge with some work on Light, or Optics, as it was then called. It was in this subject, together with Mathematics and Astronomy, that his greatest work was done.

In 1667 Newton was made a Fellow of his college (Trinity College), and two years later succeeded to the

professorship of mathematics, which he held for the next twenty-five years. Nearly all the men about whom we have been talking have been unsuccessful and unpopular during their own lifetime. This was not so with Newton. From the first his genius was recognised at Cambridge, and shortly after being made a professor there he was elected a Fellow of the Royal Society. This is the oldest and most famous of all scientific societies, and had been started during the time of Cromwell's rule in England. Charles II was greatly interested in the Society and granted it a Royal Charter in 1662. Charles was still reigning when Newton was elected a member.

When William of Orange became King of England he found the money affairs of the country in a very bad state, and the coinage in a much debased condition. An effort was made to improve this state of affairs, and Newton was offered the position of Warden of the Mint. As he was able at the same time to continue in his professorship, he accepted the offer, and carried out the work so successfully that he was promoted to be Master of the Mint three years later, with a considerably increased salary. In addition, in 1699, he was enrolled by France as the first foreign Associate of the Académie des Sciences. So you see that even during his own lifetime Newton was honoured and appreciated by all sorts of men; and yet apparently he was of a very modest and retiring nature, and often had to be persuaded by his friends to publish his important discoveries.

Now let us see what these discoveries were. I have already said that he devoted himself mainly to mathematics, optics, and astronomy. His discoveries in mathematics are beyond the ken of most of us; although 'the calculus' is becoming far more widely taught than

formerly. This was a mathematical invention of Newton's which has proved to be extraordinarily useful to modern scientists and engineers. That is one of the 'tools' which Newton made, of which I spoke earlier in this chapter.

His work in optics you will be able to follow more easily. For instance, you are probably quite familiar with the rainbow colours which are seen when light falls on the bevelled edge of a mirror or passes through a

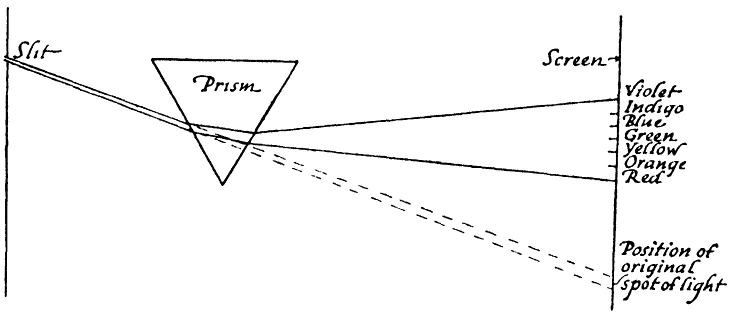


FIG. 7.—This shows how Newton obtained the spectrum

triangular piece of glass. Newton was the first man to explain correctly how those colours were produced. As a matter of fact, what he originally wanted to do was to get rid of these colours. He was engaged in making a telescope, and found that he could not make lenses which would give clear images without coloured edges. He, therefore, determined to find out just why the colours were produced, so that he might see what he should do to prevent their formation; to do this he devised an experiment whereby he obtained the colours very clearly.

Instead of a lens he used a triangular wedge of glass called a 'prism.' First of all he made a small hole in

the shutter of a darkened room, and allowed the narrow beam of sunlight which came through the hole to fall on a screen opposite (see diagram). Then he placed his prism in between the hole and the spot of light on the screen. He noticed two things. First, the spot of light moved its position considerably; and secondly, instead of being a circle of white light it became a band of coloured light nearly five times longer than it was wide. He examined the colours carefully, and found that there were seven in all—red, orange, yellow, green, blue,

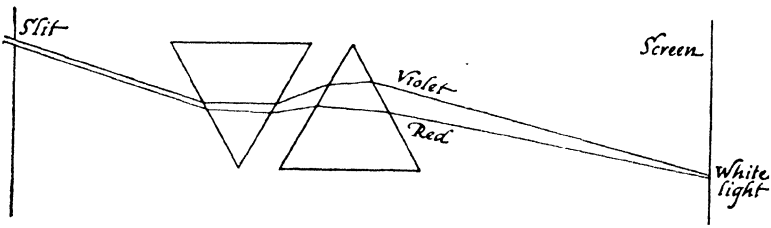


FIG. 8.—Here the colours are recombined to form white light

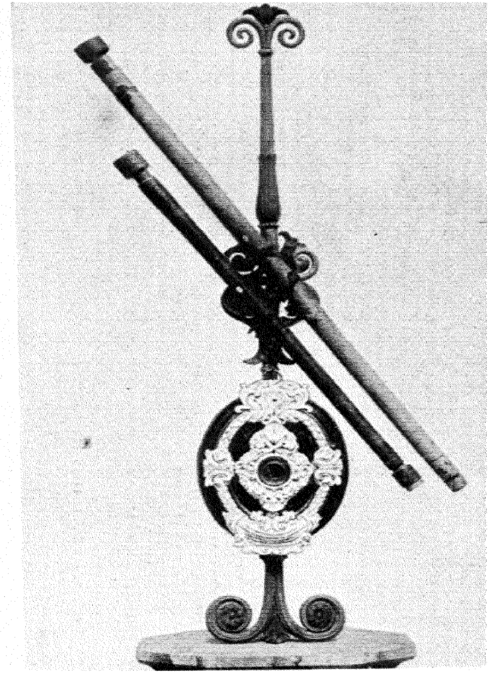
indigo, and violet. The red was nearest the original position of the spot and the violet farthest away. Thus, from his original white light Newton had separated out seven different kinds of light. Later he found that if he placed an exactly similar prism, only in a reversed position from the first, in the path of the coloured rays (see diagram), the rays recombined and formed a spot of white light.

The explanation which Newton finally came to after a variety of very careful experiments was that white light is made of seven different kinds of coloured rays. When these pass through a prism (or lens), each ray is bent, but not to the same degree. The red is bent least and the violet most, so that if the light coming from the prism

PLATE V

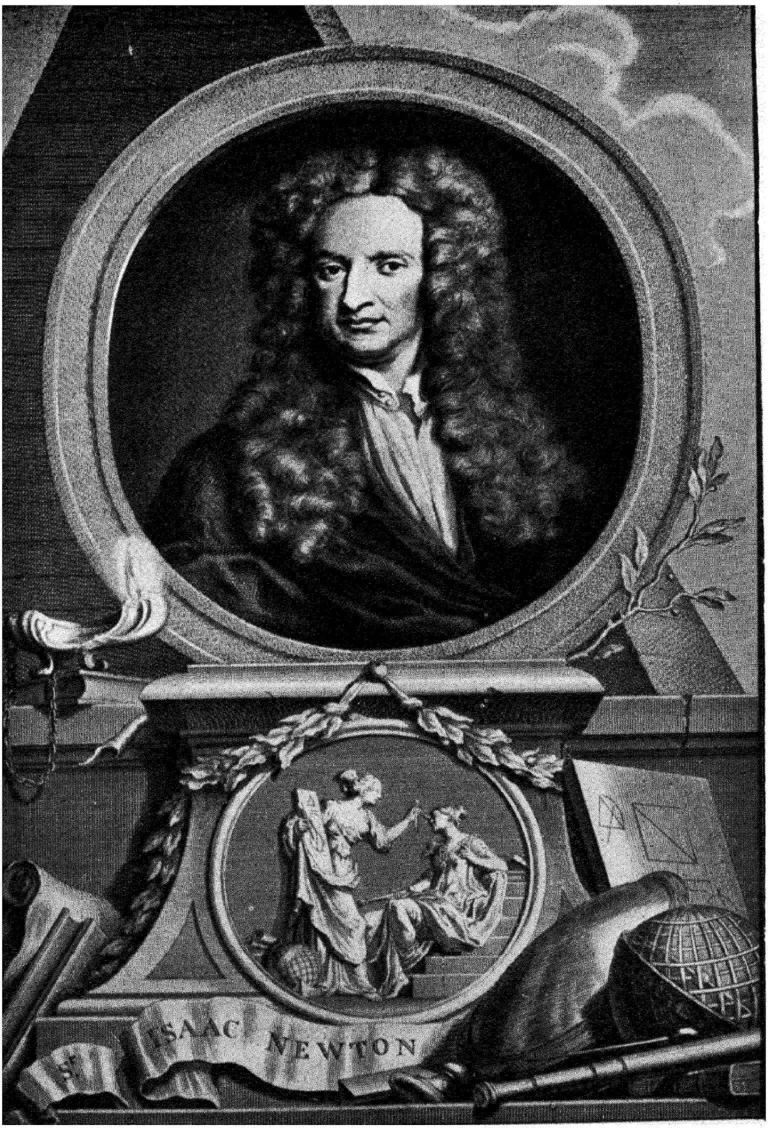
Galileo

(From a statue in the Science Museum, South Kensington)



Galileo's Telescope

PLATE VI



Sir Isaac Newton

is caught on a screen, a band of colours is produced with red at one end and violet at the other. Newton could not see how he could prevent this happening with a lens and get an image without coloured edges. He, therefore, gave up the idea of using a lens and invented a new kind of telescope, called the 'reflecting telescope,' in which he used a curved mirror instead of one of the lenses which Galileo had used in his telescope. Later, after Newton's time, it was found that the colour could be got rid of by making the lens of two different kinds of glass, so that, nowadays, good telescopes can be made on Galileo's pattern.

Now we come to the last and perhaps the most famous piece of work which Newton carried out. This was concerned chiefly with astronomy, although it necessarily included a good deal of the branch of Physics which we call 'dynamics,' *i.e.* the science of moving bodies. When he got to Cambridge, one of the first books which Newton read was that by Kepler, in which he proved that the paths of the planets round the sun were ellipses. The book greatly interested Newton, but he immediately wanted to go further and know *why* the planets moved in ellipses. He realised that there must be some force pulling each planet towards the sun, for Galileo had shown very clearly that if a body is moving it will continue to move in a *straight line* until some force either stops it or deflects it from that straight line. Since the planets were *continuously* deflected from motion in a straight line, and always towards the sun, it seemed obvious that there must be a force pulling the planets towards the sun. Newton also worked out by mathematics that the planets would trace out those elliptical paths if the force pulling them towards the sun varied

inversely as the square of the distance between the planet and the sun—that is, if the force became very much stronger the nearer the planet was to the sun. He was much occupied with this problem in the year 1665, when the University of Cambridge had been 'sent down' because of the Great Plague. The story goes that he was in the orchard at his home, turning the problem over in his mind, when an apple fell to the ground just by him. It flashed into his mind that here was a well-known example of a body being pulled by a force which obeyed that 'inverse square law' which he had worked out for the planets. (It was Galileo who had shown that falling bodies obey this law.) Now the apple was pulled towards the earth, and the planets were pulled towards the sun, but each according to the same law of force. Was it possible that each was only an example of a more general law by which all masses of matter were attracted to each other? If he were right, then he should be able to prove it by finding whether the moon's attraction towards the earth obeyed this law. He at once set about this new problem. For it he needed the following items of knowledge, all of which were available:—

(1) The distance of the moon from the earth.

(2) The time taken by the moon to make one complete revolution round the earth.

(3) The distance through which any body falls towards the earth in one second.

Newton's task was to calculate from (1) and (2) how far the moon moved towards the earth in one second. This should agree with (3) if he were right in his idea. Alas, he found that it did not, and so for the time being he was obliged to abandon his theory! A good many

years later, however, it was found that the distance of the moon from the earth, which he had used, was inaccurate. When Newton substituted the correct value in his calculations he found that the 'fall' of the moon towards the earth every second was just what it was for every other body attracted towards the earth. He had been right after all!

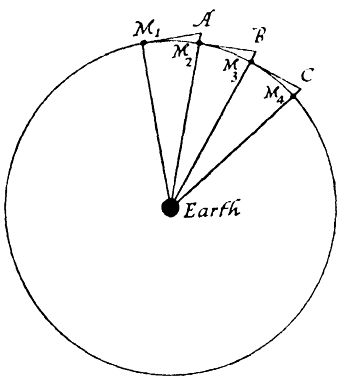


FIG. 9.—M_1, M_2, M_3, M_4 are positions of the moon after equal intervals of time. AM_2, BM_3, CM_4 show the moon's 'fall' towards the earth in each of these intervals

Let us see, now, just what Newton had done. *First,* he had explained fully Kepler's laws about the motions of planets, *i.e.* that there is a force pulling the planets towards the sun; that this force grows proportionately bigger as the square of the distance between the planet and the sun gets smaller; and that the result of the planets being pulled out of their straight-line path in this way is that they move in ellipses. *Secondly,* he showed that a force acts between all masses of matter and varies according to the distance between them in exactly the same way. The practical results of this 'Universal Law

of Gravitation' are really very well known. In the first place, all bodies above the earth which *start from rest* fall straight towards the centre of the earth. Secondly, if a body near the earth is moving relatively to it, for example a ball thrown more or less horizontally, it will trace out a particular kind of curve, called a parabola, before it finally reaches the earth. (See diagram.) Finally, if a body is moving sufficiently fast relatively to

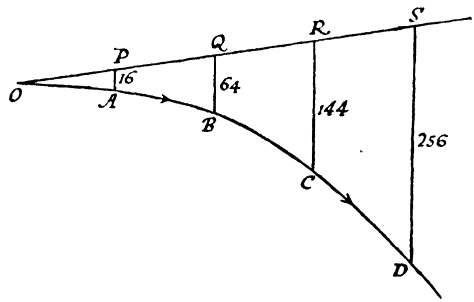


FIG. 10.—OS is the direction in which the ball is thrown; OABCD is the path along which it travels owing to the earth's pull. PA, QB, RC, and SD show the *total* fall towards the earth at the end of each of the first four seconds

another larger body, and is far enough away from the latter, it will move continuously *round* the larger body in a path which will either be a circle or an ellipse. The path of the moon round the earth is very nearly a circle.

Newton published the results of all his work in two very important books, the *Opticks* and the *Principia*. The latter is universally acknowledged to be the most important book ever published in the history of science.

As I have already said, Newton made clear the way for the great army of scientists who came after him. Hence-

forth the account is not of one road but of the many tracks comprising it. All lead towards the same goal—that is, to the complete understanding of ourselves and the world in which we live. Travellers along each bring different stories of their journeys to form separate chapters in the great book of knowledge. Some of these stories will be told in the second part of this book.

PLATE VII

The Hon. Robert Boyle

PART II

CHAPTER X

Chemistry

I

THERE are to-day in Great Britain, in the various countries of Europe, and in America, thousands of factories where all the various things we use, and which form part of our modern civilisation, are made. In almost every one of these factories one or more of the great army of industrial chemists is to be found at work in his laboratory. His work may be merely to test the purity of the materials which are being used and made in the factory; but more often it is to experiment and try to find out new and better materials or new and better ways of making them.

Every one of these chemists has been thoroughly trained for his work. He may be trying to find something new, but he knows how to set about it and is able to understand and interpret the new results he gets from his experiments. He is rather like a man with a very good map, and a very good compass, setting out to explore new country.

Now, rather under three hundred years ago there was no map of this country at all. The old alchemists of the Middle Ages had plenty to say about what they *thought* it was like, but their experiments had only explored just the outer fringe of it. Later, the followers of Paracelsus penetrated a little further, but no one knew what the country was really like.

The Hon. Robert Boyle (1627–1692).—Then, in the seventeenth century, there came a man who at least put forward a plan for exploring the unknown land of chemistry. This man was the Hon. Robert Boyle, an Englishman, born in 1627. His father was the great Earl of Cork, and Robert was his seventh son. Boyle lived through stirring times, for he was born in the reign of Charles I; lived through the Civil War and Cromwell's rule, and saw the Restoration, the Great Plague, and the Fire of London. He lived on through James II's reign, and died in 1692, three years after William and Mary came to the throne.

He was at Eton as a boy, and then lived abroad with a tutor for a good many years. While he was at Eton he was made very ill by a wrong dose given by an apothecary. This made him 'fear physicians more than the disease,' and he determined to gain for himself some knowledge of medical drugs. When his father died he returned from the Continent, and, having money and leisure, he devoted himself for the rest of his life to scientific or, as they were still called, 'philosophical' pursuits. It was about this time that the famous Royal Society had its beginnings, and Boyle was one of its earliest members. All the results of his experiments were reported to this Society, and in many of them he worked together with another member called Hooke.

Boyle was a very careful experimenter, and he very soon came to see that chemical knowledge, at that time, was in a very muddled state and that most of the views held had no foundation in fact. In 1661 he published his famous book called the *Sceptical Chymist*, and it is largely because of this book that he has been called by later generations the 'Father of Modern Chemistry.' What

is a Sceptical Chymist? A sceptic is one who questions everything and takes nothing for granted. This book of Boyle's was written as a conversation between this 'Sceptical Chymist' and two others. One of these was an upholder of Aristotle and his four elements; the other of Paracelsus and his Three Principles, of which we heard in Chapter VI, Part I.

In Boyle's book each of these two men in turn proclaims his beliefs and brings what evidence he can in support of them. Then the sceptical chymist proceeds to pull their arguments to pieces. Moreover, he describes experiments which he has done himself which show that there is no ground whatsoever for assuming that the number of elements is either three or four. In fact, says the sceptical chymist, it is quite impossible yet to fix a limit to the number of substances which can be considered elementary. The thing to do, he says, is to stop talking and repeating what somebody else has said, and set to work to find out *by experiment* just what substances are elements. By an element he explains that he means a substance which cannot be split up into two or more different parts.

Here, then, was a plan of action for the exploration of the unknown country—and it proved to be a very excellent one. Actually Boyle himself did not add a great deal to chemical knowledge; most of his experiments concerned physics rather than chemistry. What he did for chemistry was to point out the only way which could lead to any further advance into new territory. 'Search for the elements' was his doctrine, and search by careful personal observation and experiment. And for the next one hundred and fifty years chemists both in England and on the Continent carried on this search, until at the beginning

of the nineteenth century not three, nor four, but fifty chemical elements were known, while to-day the number is over ninety.

The Phlogiston Theory.—In spite of Boyle's clear call to action it was another hundred years before anything much was achieved in this direction. In those days news travelled slowly. You must not imagine that chemical philosophers everywhere knew of Boyle's book and just ignored it. It was a long time before it became generally known. Besides, it did not contain many new and exciting ideas; it merely discredited the old ones in most men's eyes. In the meantime a German chemist was teaching some new ideas which caught the imagination of all who heard of them, and quickly won many supporters.

These ideas concerned the age-old question of burning:

What *does* happen when anything burns?

Why will some substances burn while others will not?

The old idea was that 'inflammable' substances contained a lot of the fire element which could be seen escaping in the flame. The new theory was really only the old one in modern dress; but in its new form there certainly did seem quite a lot to be said for it.

This was the theory:

(1) All substances which would burn contained a substance called Phlogiston, which was really the fire-element under a new name.

(2) Substances, such as sulphur, which burnt very easily were very rich in phlogiston.

(3) All metals which changed to a powder when heated also contained phlogiston.

(The metals which do not change are gold and silver.)

(4) When substances burn, or metals are heated so

that they change to a powder (called a calx), phlogiston always escapes. This means that the metal, before heating, is made up of two different parts, the powder or calx, and phlogiston. According to this theory, then, a metal could not be one of the elements for which Boyle had told chemists to look. In fact, no substance which burnt could be an element.

This new teaching, known as the Phlogiston Theory, was a great deal better than the old ones of the Middle Ages or even that of Paracelsus. It was proved to be wrong; but there *was* a great deal of evidence in its support. Partly because of this, but also because during that time there were no really great men interested in chemistry, the Phlogiston Theory held the field for a hundred years after the time of Boyle. Then, quite suddenly, a tremendous advance was made along the way directed by Boyle.

The start was made by three Englishmen living in the latter part of the eighteenth century. Very different were these three men. *Dr Joseph Black* was a learned Edinburgh professor; *Dr Joseph Priestley* was a fervent but poor Unitarian Divine; while the *Hon. Henry Cavendish* was a wealthy nobleman, the grandson of a Duke on both sides. All three, for the greater part of their lives, were firm believers in the Phlogiston Theory.

Dr Joseph Black.—Let us first take the work of Dr Black. He was a doctor before he became a Professor of Chemistry, so that he was interested in substances from the point of view of their use in medicine. In this way it happened that he made a new white solid, magnesia alba, which he found was very like chalk.

Chalk, of course, had been known and used for a very long time. The Romans used to heat chalk in kilns to

get quick-lime which they used to make mortar. The alchemists knew that when vinegar was added to chalk it bubbled violently; it effervesced, as we say now. Another substance prepared from the ashes of a plant called 'kali' also effervesced with vinegar; and from this plant all substances behaving in this way took their name and were called *Alkalis*.

Now an odd thing was found to happen if an alkali was heated with quick-lime. Quick-lime was so called because it would burn the skin quite badly, much as would a live or quick coal. When quick-lime and an alkali were heated together, this burning property was passed on to the alkali. The latter now burnt the skin, while the lime was quite mild and inoffensive and was, in fact, once more chalk.

The obvious explanation at that time was that quick-lime was made up of chalk and a fiery substance (phlogiston) which had joined with the chalk during the heating of the latter to make quick-lime. This fiery substance left the quick-lime and joined with the alkali, when the two were heated together. The new burning kind of alkali was called a 'caustic alkali.' Both caustic alkali and quick-lime, therefore, contained two substances according to the old explanation:

Quick-lime = chalk + phlogiston.
Caustic alkali = ordinary (or mild) alkali + phlogiston.

Chalk and ordinary alkali were, therefore, obviously simpler substances than quick-lime and caustic alkali.

Dr Black found his new substance magnesia alba to be like chalk and the alkalis because (1) it effervesced with vinegar; (2) when heated with quick-lime it turned the latter back to chalk.

It was, in fact, a new mild alkali.

He next tried to find out whether, like chalk, it would become 'caustic' or 'quick' when it was heated strongly. Before heating it, however, he did something which no one had bothered to do before in this kind of experiment. He *weighed* the magnesia alba which he was going to heat. Sure enough, on being heated it turned into a substance quite like quick-lime, though by no means so burning in its properties. Then he weighed this new substance and found that it only weighed 7/12ths of the weight of the original magnesia. What had happened to the magnesia in the heating?

To try to find the answer, Black made another experiment. Vinegar, you remember, when added to the original magnesia had caused a great deal of bubbling or effervescence. He now added vinegar to this new substance obtained by heating the magnesia. *There was no effervescence.*

Black explained the result in this way. Since the magnesia lost in weight when it was heated, something had left it. Nothing could be seen leaving it, however. Now the only thing which Black could think of which could leave a substance without being seen was air, so that he came to the conclusion that some kind of 'air,' which was originally contained in the magnesia, left it when it was heated. This conclusion was borne out by his experiment with the vinegar. When vinegar is added to magnesia before it is heated, the effervescence caused must be due to bubbles of this air leaving the magnesia. Since heated magnesia gives no effervescence, the 'air' must already have been driven off by the heating.

Black's next idea was to try to get this 'air' back into the heated, or caustic, magnesia and so form his original

magnesia alba again. Now, since mild alkali also effervesced with acids he thought this probably contained the same kind of air; so he dissolved some heated magnesia in acid and then added mild alkali. From this he got a solid substance, just like his original magnesia alba, which effervesced with acids. The mild alkali had given the 'air' which it contained to the caustic magnesia, forming again the magnesia alba.

Having found out all this about magnesia alba which was so like chalk, Black obviously was led to try the experiments with chalk and see if he got the same results. He did in every respect. (1) Chalk also lost weight when heated to make quick-lime. (2) Quick-lime did not effervesce with vinegar.

The same explanation, therefore, also applied to chalk. That is to say, chalk contained 'air' which could be driven off, either by heating, or by adding acid:

Chalk = quick-lime + 'air.'

According to Black, *therefore, quick-lime is a simpler substance than chalk*. The old idea had been the other way round.

Arguing in the same way, Black showed also that the caustic alkalis were simpler substances than the mild alkalis, which could be shown to contain 'air' because they effervesced with acids.

This 'air' which is contained or 'fixed' in magnesia, chalk, and the mild alkalis, Black called Fixed Air. It is what we now name Carbon Dioxide. He was never able to collect any large quantity of it, but he showed how it could be distinguished from ordinary air and its presence recognised. Quick-lime, although nearly insoluble, will dissolve to a certain extent in water and its solution is

called lime water. In ordinary air, lime water remains clear, but a trace of Black's fixed air turns it milky. By using this test Black showed that

(1) The air which we breathe out contains fixed air;

(2) Any sugary liquid which is fermenting to form beer, wine, or an alcoholic liquor gives off fixed air; and

(3) That charcoal when it burns also forms fixed air.

We must now sum up the important points of Black's work.

1. He showed that the old idea that chalk and the mild alkalis were simpler substances than quick-lime and the caustic alkalis was wrong, since the former substances could be shown to consist of the latter joined with fixed air. For some years it was thought that the caustic alkalis and quick-lime were probably 'elements,' since all efforts to decompose them failed. We shall hear later how their decomposition was brought about by using an electric current.

2. He discovered a new kind of air, fixed air. This was the first time anyone had really recognised a kind of air distinct from common air. Priestley followed up this part of his work with very great success.

3. Finally, and *most important of all*, for the first time he weighed the substances with which he worked and drew his conclusions from the results of these weighings. If a substance weighs less than the one from which it was made it must be a simpler substance (provided always, of course, that the person who does the weighing is known to be careful and accurate!).

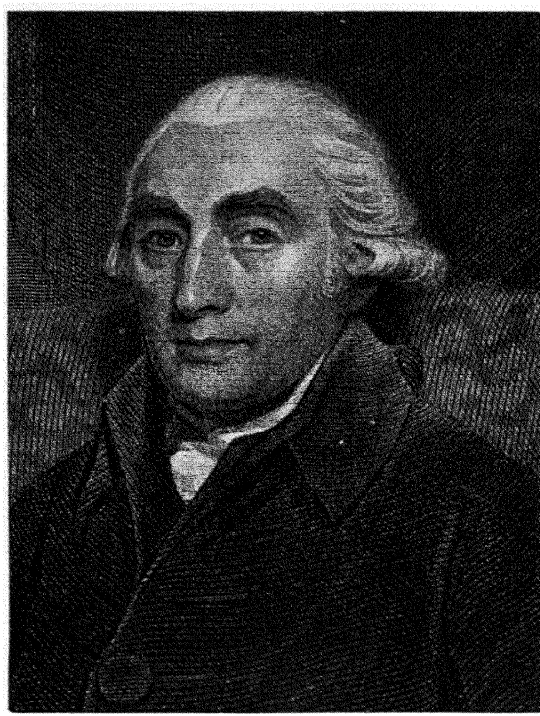
Joseph Priestley (1733–1804).—Both the other members of this famous trio of British chemists were extremely

interesting characters. Joseph Priestley was born near Leeds in 1733 of quite poor parents. He was brought up very strictly and trained to be a Nonconformist Minister. He was not very popular with the people of his first chapel and turned to teaching instead. Soon after he married, he met a man named Benjamin Franklin, whom we shall hear of again for his discoveries in electricity. This friendship turned Priestley's interest to scientific subjects, and he started experiments on his own with such success that he was soon made a Fellow of the Royal Society. After an interval, in charge of another chapel, Priestley became librarian to the Earl of Shelburne, and then had much more time and leisure for his favourite hobby. Here he wrote many treatises on his scientific work and also a great many theological tracts. These latter were of a somewhat unorthodox nature and violent in tone, and he was eventually obliged to leave the Earl of Shelburne and take charge of a chapel in Birmingham. Here once again he got into trouble; this time because of his sympathies with the Revolution which had broken out in France. An angry mob stormed his house and destroyed much of his property, and he was forced to flee, first to London and eventually to America, where he died in 1809.

The Hon. Henry Cavendish.—The Hon. Henry Cavendish was a man of very different nature. He was very wealthy, and owned two or three houses in London, each devoted almost entirely to his scientific pursuits. He hated society, and rarely went out, except to the regular dinners and meetings of the Royal Society Club. He had a horror of women, and, it is said, would not have one in his house even as housekeeper.

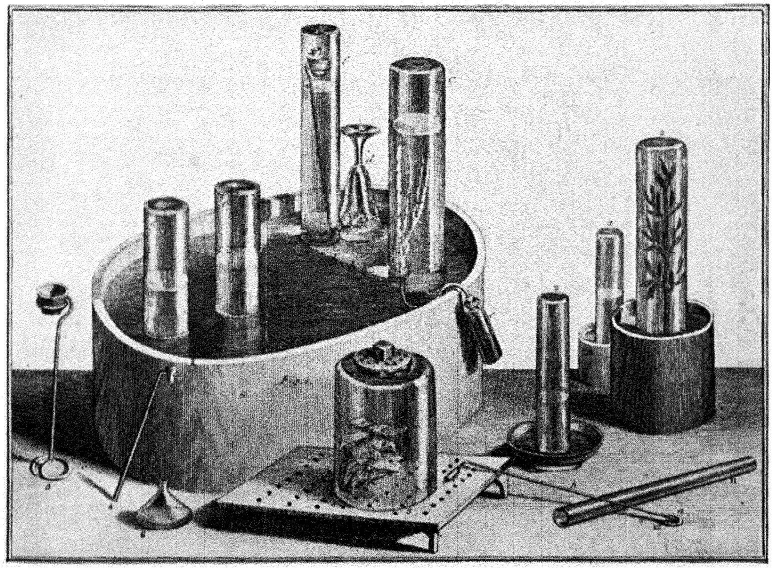
His scientific achievements were by no means limited

PLATE VIII



Dr Joseph Black

The Hon. Henry Cavendish



Dr Joseph Priestley and his Pneumatic Trough

to chemistry. In the study of electricity, and in most other branches of physics, his name occurs as one of the great early investigators. His passion was to measure everything, and because of this he ranks with Black as one of the great pioneers of the new era.

In the story of chemistry the names of Cavendish and Priestley are linked with two great pieces of work. In each of these one of the original 'elements' of Aristotle is shown to be, after all, not a single simple substance. The first of these was air. Here both men played a part. The second was water, and here the work was carried out almost entirely by Cavendish.

New Kinds of Air.—Until the time of Boyle there was thought to be only one kind of air—the common air which is all about us. True, that air often seemed to change in some of its qualities, more especially in the matter of smell; but this was always put down to the presence of impurities with which it had become impregnated. Boyle, in one of his experiments, found that when iron dissolved in an acid substance, called oil of vitrol, there was a great deal of effervescence, and the air which came off would burn if a candle were held to it. Boyle must have realised that this air was not the same as ordinary air, but, as far as we know, he did not say so. As we have seen, it was Black who first recognised that there might be different kinds of air.

One of the first pieces of work carried out by Cavendish was to show quite clearly that Boyle's 'inflammable air' and Black's 'fixed air' really were completely different substances from ordinary common air. This he was able to do by measurement with weighed bladders filled with each kind of air in turn. He found that the inflammable air was only 1/11th of the weight of the same

volume of common air; while 'fixed air' was more than one and a half times as heavy. Here, again, we see how important it was to get the weights of substances and how clearly the results showed up directly they were obtained.

You will remember that Black found that his 'fixed air' was given off from a fermenting liquid. Priestley's interest was turned to the subject by the presence, near his house in Leeds, of a brewery, so that a plentiful supply of this fixed air was available. He did not learn a great deal more about this gas than did Black, although, incidentally, he discovered how to make 'soda-water' by forcing it into water.

Priestley is famous for the apparatus he devised to collect these new airs. He made them displace water or mercury from jars inverted in a big trough of the liquid. This he called a pneumatic trough, from the Greek word 'pneuma,' meaning air. Gases which do not dissolve in water are always collected in this way now. Priestley generally used mercury rather than water. (See Plate IX.)

After making fixed air and inflammable air by the same methods as Cavendish had used, Priestley then tried to make further new airs by mixing other metals with other acids. An acid is a substance which, like vinegar, makes chalk effervesce and which turns a certain purple substance, called litmus, red. He also tried heating a variety of solid substances strongly to see if he could get a gas. As a result of a number of experiments he succeeded in obtaining several new gases or 'airs.' These were what we now call the three oxides of nitrogen, hydrogen-chloride, and ammonia. The two latter he called marine acid gas and alkaline air.

His most famous discovery, however, was that of the

gas which is now called oxygen, but which he called 'dephlogisticated air.' He had procured a new and large magnifying or 'burning' glass which he used to heat substances. He did this by focussing on them the sun's rays through the glass. The substance was enclosed in a bottle of mercury inverted in a trough of the same liquid. One of the substances which he heated was the red powder got by heating mercury for a long time in air. This was known as Red Mercury Calx. To his great delight Priestley found that an air (or gas[1]) was very readily expelled from this substance which, at the same time, again formed mercury. He collected several jars of the gas and set about examining its properties in the ways he usually employed. To begin with, he found that a candle burnt in it very brightly indeed, far more so than in common air; while a piece of glowing wood sparkled and flared and burnt away completely. A mouse placed under a vessel filled with this new gas lived twice as long as it would have done if the jar had been filled with ordinary air. Priestley himself, on breathing the air, fancied that his 'breast felt peculiarly light and easy for some time afterwards.'

Priestley was a very firm believer in the Phlogiston Theory and always tried to explain his experiments in its light. A candle, if placed in a closed vessel, will burn for a little while and then go out; even though there is plenty of candle left to burn. According to the Phlogiston Theory the explanation of this was that the air could only hold a certain amount of phlogiston. Once the air was saturated nothing could burn in it, since burning was always accompanied by the giving off of phlogiston.

[1] The term 'gas' was introduced quite soon and the word 'air' kept to denote ordinary atmospheric air.

Priestley explained the extraordinary ease with which substances burnt in his new air by supposing that it contained absolutely no phlogiston itself. It, therefore, took up the phlogiston of burning substances very readily. On the other hand, he said, common air must contain some phlogiston since it required a much shorter time to become saturated. The new gas was, therefore, common air without phlogiston, or 'dephlogisticated' air.

So we see that Cavendish and Priestley showed quite clearly that common air is by no means the only kind, but that a number of totally distinct airs exist. As we have said, these are now known as gases.

The Compound Nature of Water.—Both Cavendish and Priestley were interested in the new science of electricity and each possessed a machine for making electric sparks. Priestley one day thought he would try the effect of sending a spark through a mixture of inflammable air and common air. He found that after the spark a kind of dew had formed on the walls of the vessel. Cavendish heard of this experiment and repeated it on a larger scale. Instead of common air, however, he used the new dephlogisticated air (oxygen). By using large quantities and sending repeated sparks Cavendish was able to collect a fair amount of the dew which Priestley had noticed. He tested this in every way he could think of, and came to the conclusion that it was pure water. Water then could not be a simple elementary substance since it was made from two different substances:

$$\text{Water} = \underset{\text{(hydrogen)}}{\text{inflammable air}} + \underset{\text{(oxygen)}}{\text{dephlogisticated air.}}$$

So yet another of Aristotle's elements was proved to be no element at all!

II

Lavoisier (1743–1794).—While these three great chemists, Black, Cavendish, and Priestley, were carrying on their investigations in England, there was living in France a man who was destined to do even greater things for chemistry. This man was Jean Antoine Lavoisier. He was born in 1743 of middle-class parents and received a very good education. At first he studied law, but soon the attraction of mathematics and physical science made him decide to devote himself entirely to their study. Quite early his work gained for him admission to the French Académie des Sciences, which is the equivalent of the Royal Society in England. When he was about twenty-six, he decided that, to carry out his one aim in life, which was the advancement of science, he needed a larger income than that derived from his small private fortune. To this end he took a step which eventually brought his brilliant career to an untimely end.

There was in France, during that time of oppression preceding the Revolution, a financial company known as the 'Ferme Général,' which undertook to collect for the government all kinds of taxes and duties on various commodities. Lavoisier, in order to increase his income, became a member of this company. There is no doubt that a great deal of corruption and oppression accompanied this collection of taxes, and many of the company's agents did very well for themselves out of it. Later, when the Revolution came, it is hardly surprising that its members came in for their share of unpopularity. It is quite certain, however, that Lavoisier invariably carried out his duties in an entirely honourable manner; in fact, he did all in his power to remove many of the obvious

abuses. Nevertheless, the temper of the revolutionaries was not such as to distinguish between individuals where the records of the company as a whole were so black. We are, however, anticipating.

There were some twenty years between Lavoisier's appointment as a *fermier général* and the outbreak of Revolution. It was during these years that his greatest work was done. In 1771 he married a very charming and intelligent young wife, who helped him in his work. When he published his famous book, *Traité de Chimie*, it was she who made the plates for the book. In each of the two well-known pictures of Lavoisier in his laboratory his wife is also to be seen.

Like nearly all famous men, Lavoisier had jealous enemies. It was these enemies who, during the Revolution, helped to pile up false evidence against him. In 1791, two years after the storming of the Bastille, he was arrested and condemned to the guillotine. A plea was put forward that as a scientist employed, as he was then, on public work in connection with weights and measures, a reprieve should be granted. Then came the often quoted reply: 'La Republique n'a pas besoin de savants, il faut que la justice suive son course.' ('The Republic has no need of learned men, justice must follow her course.') Lavoisier was, therefore, beheaded. 'A moment was all that was necessary in which to strike off his head, and probably a hundred years will not be sufficient to produce another like it.' So said another famous scientist, and perhaps he was not far wrong.

Before describing his actual experiments we will sum up briefly those achievements of Lavoisier which were the cause of such high praise from one of his own time.

1. He showed clearly that the old Phlogiston Theory

of burning was all wrong. In its place he put forward a new one which was so obviously right that all the chemists of the time (with the exception of Priestley) eventually came over to his way of thinking.

2. He drew up a list of about thirty substances which he considered to be elements, putting them into three classes according to their chemical behaviour with each other.

It is undoubtedly the first of these for which he is most famous; but the second was very important, for it tidied up prevailing ideas and enabled chemists to take stock of their knowledge. We might perhaps describe it as the first sketch map which was made of the new country which was being explored.

Now let us turn to the first achievement and see how it was accomplished. At once it must be emphasised that Lavoisier's success was due above all to the fact that at every step of the way he *measured* the quantities of the substances with which he was working. This he did either by weighing them or by measuring their volumes.

We will begin with some experiments which Lavoisier did before Priestley discovered that wonderful new gas 'dephlogisticated air,' or oxygen as Lavoisier was to call it. First, as the result of a great many experiments, he established the following facts:—

(1) A metal increases in weight when it is heated to form a calx. (This was not new knowledge, but a fact of which little notice had been taken.)

(2) Sulphur and phosphorus (which are *not* metals) also increase in weight when they are burnt.

(3) When phosphorus is burnt in a limited supply of air, part, but only part, of the air disappears. The remaining air will not allow the rest of the phosphorus

to burn, and also puts out the flame of a candle. (This is the famous 'Bell-Jar' experiment which everyone who has done any chemistry at all will have seen performed.)

At this stage Lavoisier heard of Priestley's discovery. There is no doubt that he thereupon saw immediately the true explanation of the facts; if, indeed, he had not

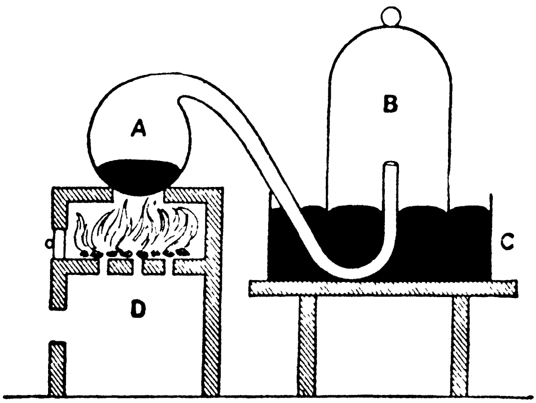


FIG. 11.—Lavoisier's experiment to prove his theory of burning. A, retort containing mercury heated by charcoal furnace (D). B, Bell jar in trough of mercury (C)

already done so. He at once devised the following experiment which should make it absolutely clear to everyone that his ideas were right:—

(1) He took a retort with the neck bent up at the end, as shown in the diagram, and in it he placed 4 *ounces* of pure mercury.

(2) He placed the retort with the end of the neck leading into a bell jar inverted over mercury (see diagram). The total volume of air enclosed in the retort and the bell jar together was 50 cu. ins.

(3) He heated the retort for twelve days. During

that time a red scale (Priestley's red mercury calx) formed on the mercury.

(4) The mercury meanwhile had risen in the bell jar, reducing the volume of air to 42 cu. ins., *i.e.* *8 cu. ins. of air had disappeared.*

(5) He collected the red mercury calx and weighed it. It weighed 45 grains.

(6) He put this red mercury calx into a small retort and heated it, collecting the gas evolved in the usual way. In this way he obtained 41½ grains of mercury and 8 *cu. ins. of air* which, on testing, he found to be identical with Priestley's dephlogisticated air.

Note.—The 8 cu. ins. of air, which had disappeared during stage 4, had now been regained and found to be this new gas.

(7) He was able to calculate the weight of the 8 cu. ins. of gas, when he had found its density, and this was exactly equal to the weight lost by the red mercury calx when it was heated, *i.e.* 3½ grains.

What now was this new theory of burning which these experiments proved? First, common air is made up of two different gases; an active one which Lavoisier called Oxygen; and an inactive one which he called Azote. Secondly, when anything burns in air, the oxygen joins with the thing which is burning to form the new substance. In the case of a metal the calx is formed. The calx of a metal, therefore, is not simpler than the metal, but consists of the metal joined to oxygen. The metal is the simple substance. This is a very simple explanation, as you see, and its great merit is that it explains all the facts; not a single fact to do with burning has ever been found which does not fit in with this theory.

Priestley discovered a great many new gases, as we have seen, and named them. But, being a firm believer in the

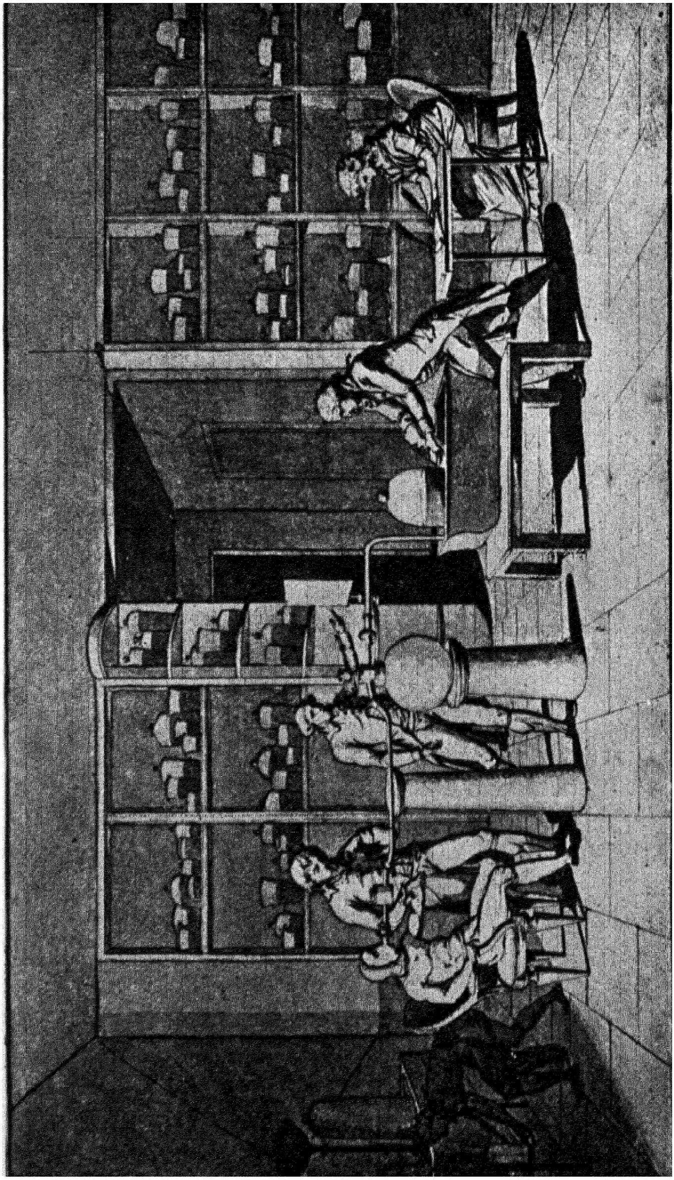
Phlogiston Theory, many of the names Priestley gave to these gases did not mean anything in the light of the new theory. One of the things Lavoisier did in the general tidying up was to give appropriate names to the many new substances which had been discovered. He also renamed most of the old ones to fit into his general scheme. Hydrogen was so called because it produced water; azote means inactive. In England we now call this last gas nitrogen, but it is still called azote in France. Nearly all the names of chemical substances which are now met with in chemistry were originally given by Lavoisier. He made one mistake. Oxygen had proved to be such an important gas in connection with burning, that Lavoisier was led to overestimate its importance as a whole. He was convinced that oxygen was to be found as the essential element in all acid substances. The name oxygen, which he gave it, means 'acid producer.' It is now known that all acids do not contain oxygen. Moreover, it has been found that it is hydrogen that is the element common to all acids. All the same, this mistake is almost the only one that we can hold up against Lavoisier. He was a *very* great scientist.

Finally, Lavoisier drew up a list of those substances which, so far, had resisted all attempts to split them into simpler parts and which, therefore, for the meantime at any rate, might be called elements. Here are some of the substances which he included in his list:

Light	Sulphur
Heat	Phosphorus
Oxygen	Carbon
Azote	Lime
Hydrogen	Magnesia

All the metals.

PLATE X



Lavoisier in his Laboratory

(*From a drawing by Mme Lavoisier*)

Notice that he did not include the caustic alkalis although he did include lime. The caustic alkalis had not yet been split up, but Lavoisier thought it very probable that they were not elements.

Of the four men of whom we have been speaking, Black, Cavendish, and Priestley lived in the same country, while Lavoisier in Paris was not so very far away. The first three were members of the Royal Society, and the latter of the French Académie des Sciences, so that their work was well known. Though communication between them was by no means so easy and so frequent as between scientists of to-day, they were each fairly well informed of the work of the others. As we have seen, early experiments by Priestley were the starting-point of Cavendish's great work on the composition of water; and his discovery of oxygen gave Lavoisier just that bit of information he needed to make his theory of combustion complete.

Karl Wilhelm Scheele (1742–1786).—While these more famous chemists were making and publishing their discoveries in England and France, farther away, in Sweden, a poor apothecary, Karl Wilhelm Scheele, was working on much the same lines and obtained independently many of these results. He actually prepared oxygen two years before Priestley carried out his famous experiment (1774), but was not able to publish his work until 1777. It was not until that year that he heard of Priestley's experiment. Scheele was, therefore, the true discoverer of oxygen, although Priestley's name is inseparably connected with it. Because of his struggles with poverty and ill-health the real merit of Scheele's work was not made known to the world until considerably later, so that he influenced less than his contemporaries the immediate future of

chemistry. Nevertheless, his contribution was worthy of great respect, and his name must not be forgotten. In addition to his discovery of oxygen he also discovered that very remarkable green gas, chlorine. He isolated a great number of acids which occur in various plants and fruits, and are known as 'vegetable acids.' Besides this he did a great deal more work which proved to be of the greatest value to building up the science of chemistry; though to enumerate the various discoveries would convey little to you now. Only towards the end of his life did he receive the recognition he deserved. We know that he was then in communication with Lavoisier. Unfortunately his health was very bad, probably because of his early privations; and in 1786 he died at the comparatively early age of forty-four.

Sir Humphry Davy (1778–1829).—Lavoisier, in setting out his list of those substances which he considered to be elements, had summed up and rounded off the work of the previous one hundred and fifty years which had been initiated by Boyle. Most of the substances in his list are still classed as elements, but a few had to be removed and many more added during the next hundred years. The man who did most towards correcting Lavoisier's list was Sir Humphry Davy, a popular and successful English chemist. Davy was a Cornishman, born in Penzance in 1778. He was a boy of sixteen at the time of Lavoisier's death. In the following year he was apprenticed to a surgeon and apothecary in Penzance and began studying for the medical profession. He was at this time a great reader of a variety of subjects, and was not afraid to wield his own pen both in prose and verse. In 1797 he read a copy of Lavoisier's famous book on chemistry, which so fired his enthusiasm that he began

making experiments of his own with such materials as were available in the surgery. His work at that time led to nothing of great note, but the essays which he published on it brought about his appointment to the Pneumatic Institution at Bristol. Here the effect of the many new gases which had recently been discovered were being tried on invalids in the hope of effecting cures. This appointment gave Davy far more opportunity for his own experiments and he soon gained a name for himself in the scientific world. It was here he discovered the peculiar properties of one of the gases discovered by Priestley which enabled it to be used as an anæsthetic. This is the familiar 'Dentists' gas' still used to-day.

Meanwhile, in London, the efforts of a certain Count Rumford (who, a little later, married Lavoisier's widow) had led to the establishment of the Royal Philosophical Institution. This was designed to help scientific research, and also to provide lectures for the general public on the discoveries which were made. These lectures are still continued to this day. All branches of science were to be represented, and in 1801 Davy was invited to become assistant-lecturer and experimenter in chemistry. He was then twenty-three years old. The whole of the rest of his life was spent in connection with the Royal Institution. Fame and honours came quickly, and he was soon a popular member of London society. In 1811 he became Sir Humphry Davy, and almost at the same time he married a wealthy widow who made his position in society still more secure. Two years later, in spite of the fact that England and France were at war, he obtained permission from both governments to travel on the Continent with his wife and his laboratory assistant, young Michael Faraday, of whom we shall hear more

later. There were, both in France and Italy at that time, a number of very famous men working in all branches of science. During his tour Davy visited almost all of them, exchanging views and often continuing his own work in their laboratories.

Soon after his return to London, Davy investigated the cause of the serious explosions which were then continually occurring in coal mines. As a result he invented the famous 'safety lamp' which afterwards always went by his name. This won him a very handsome gift from the colliery owners, and in 1818 he was made a baronet. Two years later he was elected President of the Royal Society, and continued to hold the office for the next seven years. His health then began to decline, and he spent much time in the south of Europe, still carrying on his experiments. He died abroad in 1829.

Davy's researches were not limited to chemistry, but it is his chemical discoveries for which he is most famous and with which we are now concerned. Lavoisier, mistakenly as it turned out, thought that all acids contained oxygen as the acidifying principle. Scheele had discovered the gas chlorine, and another French chemist, Berthollet, had shown that chlorine was present, combined with hydrogen, in the acid which was then known as muriatic or marine acid, because it was made from salt. We now call it hydrochloric acid. Because of this fixed idea of his, Lavoisier felt sure that chlorine must contain oxygen. Instead of putting chlorine itself in his list of elements he predicted that when chlorine could be decomposed a new element would be found combined with oxygen. But in spite of all the efforts of a number of chemists chlorine stubbornly refused to yield either oxygen or a new substance; it would not

be decomposed. Davy, in his turn, carried out all the experiments he could devise, and finally announced it as his opinion that chlorine could not be decomposed and was, in fact, itself an element. This obviously meant that Lavoisier was wrong in his theory that all acids contained oxygen, since one of the commonest acids contained only two elements, hydrogen and chlorine, and no oxygen.

Davy was also concerned in the discovery of iodine and its classification as an element. He recognised its similarity to chlorine, and predicted that another similar element, fluorine, would be discovered from an acid which he had isolated and which was very like hydrochloric acid. Fluorine was later isolated, and also another element, bromine, which, together with chlorine and iodine, make up the 'Halogen Family.'

Although the caustic alkalis, which Black had shown to be simpler than the mild alkalis or carbonates, had not been decomposed into any still simpler substances, Lavoisier did not believe that they were elements and did not include them in his list. He did, however, include quick-lime and four other similar substances known as earths. Perhaps Davy's most famous achievement was the decomposition of all except two of these substances. He had at his command, however, an aid which was not available to earlier chemists.

In 1790 the Italian scientist Volta made his famous voltaic pile from which a continuous electric current could be obtained. Some years later two English chemists found that the current could be sent through water. In doing so, however, they found that it decomposed the water into its elements, hydrogen and oxygen. The latter was given off in bubbles at the wire

where the current entered, and the former at the wire by which the current left the water. Gases had already been decomposed by an electric spark; here was a way of decomposing liquids.

On arriving at the Royal Institution in 1801 Davy at once constructed a battery and set about investigating this newly discovered decomposing power of an electric current. It was not, however, until 1807 that he made any outstanding discovery. First of all he tried passing the current through strong solutions of caustic alkalis. He only succeeded in decomposing the water of the solution; that is, he only got hydrogen and oxygen. Then he passed the current through *melted* caustic potash alone. He was evidently on the right track this time, for he got an intense light and a column of flame at one wire. He guessed that he was getting something new, but that the new substance caught fire at the temperature at which he was working. He, therefore, decided not to melt the potash first but to let the current do the melting. After that he was successful. Where the negative wire (where the current left) touched the potash, small globules of a shiny metallic substance collected. Some of these still burnt with a bright flame as soon as they were formed. He examined this new substance very carefully and came to the conclusion that, although in many respects it was unlike the better-known metals, yet it undoubtedly was a new metal. He gave it the name Potassium. Similar experiments with caustic soda, quick-lime, and the earths known as magnesia and baryta, resulted in the discovery of the new metals, sodium, calcium, magnesium, and barium. All of these had to be added to the list of elements, while lime and the earths had to be removed.

III

Chemical Theory.—The work of Davy may be said to close a chapter in the history of chemistry. The majority of the elements had now been identified; and the possible methods of decomposing substance all more or less investigated. Meanwhile a new chapter was opening. The elements themselves having been determined, chemists began to inquire how and according to what rules they combined together to form compounds. Now a plan of action is always imperative in order that a real advance may be made. All scientific inquiry nowadays proceeds according to a well-recognised plan.

Firstly, all the known facts that can have any bearing on the question are collected together and reviewed. Secondly, a theory is invented which will explain all the known facts; this is generally called an hypothesis. Thirdly, assuming the hypothesis to be true, it is then seen what new results should follow from the theory. Lastly, experiments are then devised which should give these results if the hypothesis is a true one. The more conclusions that are supported by experiment the more likely is the hypothesis to be true. One contrary fact, however, must lead, if not to a new hypothesis, at any rate to a revision of the old one.

In the investigation which forms the subject-matter of this new chapter in the history of chemistry, the facts to be reviewed were, for the most part, supplied by those chemists whose work we have so far discussed. The theory which was to explain these facts was produced by an English chemist named *John Dalton*, while the further experimental evidence necessary to establish the theory was gained by a group of brilliant Frenchmen, the direct

successors of Lavoisier, and by a very eminent Swedish chemist, Berzelius.

The famous Atomic Theory of Dalton has proved to be one of the most successful and comprehensive scientific theories ever put forward. So much evidence has accumulated in its favour during the years which have elapsed since it was first advanced that it has acquired almost the certainty of fact.

Law of Conservation of Mass.—First of all let us see what were the chief facts which Dalton had to explain by his theory. Since Black first laid such stress on the importance of weight in his experiments, all chemists had tacitly assumed that during a chemical reaction the sum of the weights of the reacting substances was always equal to the sum of the weights of the products. In other words, although the original substances apparently disappeared and new ones took their place, the weight of matter always remained the same. Lavoisier did very careful experiments to show that this really was so and that no matter was lost. This principle is generally known as the 'Law of Conservation of Mass,' and is stated thus:

Matter can neither be created nor destroyed.

Law of Constant Proportions.—Just before Dalton put forward his theory, a great controversy had been going on between two French chemists, Proust and Berthollet. The question at issue was whether a compound, such as iron sulphide, which was known to consist of the elements iron and sulphur, always contained those elements in the same proportion by weight. Proust said 'Yes'; while Berthollet said 'No, it all depends on the proportions in which they are mixed before combination takes place.' Each, of course, brought forward evidence in favour of his

view, but in the end Proust won, and his view was generally accepted. This became known as the 'Law of Constant Proportions,' and stated that:

Every compound contains the same elements combined together in fixed proportions by weight.

Dalton's Atomic Theory.—Now we come to Dalton's atomic theory. The conclusions he arrived at may be set out in five points:

(1) All matter is composed of small particles called atoms, which are indivisible.

(2) An element is made up of atoms which are all exactly alike in every respect. This means that they have all the same weight. This weight is different from the weight of the atom of any other element.

(3) Atoms can neither be created nor destroyed.

(4) The atoms of elements join together in small whole numbers to form compound atoms (or molecules).

(5) The molecules of any one compound are alike in every respect, and differ from the molecules of every other compound.

Careful thought will show that point 3 explains the Law of Conservation of Mass and points 4 and 5 the Law of Fixed Proportions.

This theory of Dalton's is, of course, by no means new. Originating with the Greeks, the conception of the atomic structure of matter is one of the oldest in existence, and Dalton knew it. Moreover, it was the theory which both Boyle and Newton used constantly to explain and picture to themselves the inner workings of things. The practical value of Dalton's version of the theory was that he put it

in such a way that deductions could be made from it which could be tested by experiment. There is no need to go into details. The various laws of chemical combination can all be deduced from the Atomic Theory, and the majority were shown to hold good experimentally by that group of French chemists already mentioned.

Atomic and Molecular Weights.—Dalton had laid stress on the point that the weight of its atom was a very characteristic property of an element. An atom cannot be seen even with the most powerful magnifying apparatus invented, and it is obviously impossible to weigh an individual atom, although its weight has lately been calculated. Realising this, the chemists of the last century set out to find only the relative weights of the atoms. Hydrogen was the lightest substance known, so that the weight of its atom was taken as unity, and the atomic weight of an element defined as the number of times heavier its atom was than an atom of hydrogen. Similarly, the molecular weight of an element or compound is the number of times heavier its molecule is than an *atom* of hydrogen.

For the next sixty years chemists all over Europe were occupied in devising ways of determining molecular and atomic weights and setting up an accurate table of these weights. The man who led the way was the great Swedish chemist, Berzelius. To him also we owe the system of chemical symbols, formulæ, and equation which is such a bugbear to so many beginners in chemistry, but such a boon when once mastered!

Classification of the Elements.—The result of the sixty years' work was that, the atomic weights of the various elements having been determined, a complete scheme of classification was possible simply by arranging the elements

in the order of their atomic weights in rows of eight. In this way it was found that all the elements in the same family, such as the halogens, came in the same vertical row, with the active metals on the left, and the active non-metals on the right. A great variety of other points of resemblance and difference were also brought out which it is quite impossible to enlarge upon. The point to be emphasised is that here at last was a complete and accurate map. This was the result of the careful and ordered exploration of the unknown country which had been projected by Robert Boyle. How it would have delighted him to see the fruit of his labours!

Although this seems a fitting end we cannot leave the story here, but must go back and see how one portion of this country at first seemed to defy all efforts at exploration. Once penetrated, however, it proved to be a veritable storehouse of untold wealth.

Rise of Organic Chemistry.—The chemists of the eighteenth century distinguished between two classes of substances, those found in inanimate nature and those derived from living tissues, either vegetable or animal. The former are commonly known as inorganic substances and the latter as organic. Inorganic substances were comparatively easy both to analyse and synthesise (that is, build up from their elements) once the general methods of procedure had been mastered; but organic substances, while easily analysed, for a long time resisted all attempts to synthesise them.

Scheele isolated and examined a large number of vegetable acids, as we have seen; Lavoisier analysed alcohol and showed how it was produced by fermentation from sugar. A few years later it was established that the majority of organic compounds, such as alcohol, sugar,

ether, oils, fats, and the vegetable acids, all contained carbon and hydrogen with a varying amount of oxygen. It was generally thought, however, that some vital, or 'life,' force was necessary to make these substances, and that they could never be made in the chemist's laboratory. This belief was shattered in 1828, when a German chemist, Wöhler, prepared from inorganic materials a well-known organic substance. This was urea, a substance found in urine. This achievement opened up new vistas, and a number of chemists devoted themselves entirely to the study of organic chemistry. The chief fact which emerged as a result of this investigation was that the molecules of organic compounds are extremely complicated and contain a great number of atoms. That is why, of course, it is so much more difficult to build them up from their elements. To take sugar as a common and comparatively simple organic substance, it was found that its molecule contained twelve carbon atoms, twenty-two hydrogen atoms, and eleven oxygen atoms!

The next thing to be found out was that the skeleton of the molecule of every organic substance was made of carbon atoms, with the oxygen and hydrogen hung on outside, as it were. The carbon atoms might be in open chains or in closed rings. The benzene molecule consists of a ring of six carbon atoms each with a hydrogen atom attached; naphthalene, of which you may have heard, contains two such rings stuck together, while others even have three rings. Occasionally an atom of nitrogen is found in the ring as well. It was very soon found that it was the hydrogen or oxygen atoms hanging on the outside of these rings or chains that gave the substance its special properties. Thus all the compounds with a straight chain of carbon atoms and only hydrogen

attached to the chain are very much alike, and as a matter of fact form the mixture of substances in crude petroleum. If there are not many carbon atoms in the chain the result is a light inflammable liquid such as petrol, but a great many carbon atoms give rise to solid paraffin wax. Methods were soon devised for changing the hydrogen atoms for those of other elements or groups of elements well known in inorganic chemistry. You will see at once the immense possibilities opened up. New organic compounds (or carbon compounds as they should be

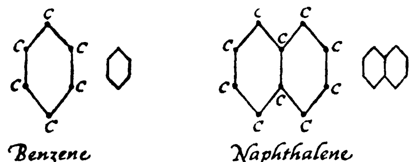


FIG. 12.—Showing the rings of carbon atoms in the molecules of benzene and naphthalene, with the simple hexagons by which they are usually represented

called, since many have never been found in living tissue) must have been discovered at the rate of hundreds a year during the last sixty or seventy years, and they are not all exhausted yet. It is these compounds which form the basis of the thousands of medicines and drugs prescribed by doctors and manufactured by great firms like 'Borroughs & Wellcome' and 'Boots Pure Drug Co. Ltd.' Then there are all the artificial dyes, including the so-called aniline dyes, based largely on rings of carbon atoms, and so on. All this brings us back to the point from which we started—that is, to the hundreds of laboratories attached to industrial firms all over Europe and America. New discoveries are still being made, but the way of the modern chemist has been made easier by his great heritage.

CHAPTER XI

Magnetism and Electricity

I

It may seem difficult for those who have grown up in this 'all-electric' age to realise that it is not so very long ago that the electric light and the telephone were expensive luxuries only to be found in the houses of the wealthy. Electric trams (which are now being scrapped wholesale!) only came into use during the first few years of this century, and the electric trains much later still. The telegraph is of longer standing; but, taken as a whole, electricity has played its part in the everyday life of the people for little more than half a century. Yet the very elementary knowledge out of which all these marvellous inventions have grown was held by that earliest of the Greek philosophers, Thales, and probably by others before him.

We have already seen what that knowledge was. In the earth there was to be found a hard blackish stone, which had the peculiar property of attracting towards itself bits of iron. Another substance, amber, behaved in a rather similar way. When rubbed, it would then pick up by 'attraction' anything which was very light. That was really all that was definitely known. As there was no obviously practical use to make of this knowledge, the matter, as far as real investigations went, rested there. There was, however, something savouring of the supernatural in the curious behaviour of these two stones. It is not therefore to be wondered at that many stories grew up of their magical power, and of the wonders that could

be performed by their aid; and later they became part of the stock-in-trade of magicians, astrologers, and alchemists of the Middle Ages. The Latin name for the black stone which would attract iron was 'magnes,' from which we get our modern word magnet. The name was probably given because the stone was found in great quantities in a district in Thessaly known as Magnesia.

The Mariners' Compass.—Somewhere about the eleventh century a really useful fact was discovered about this Magnesian stone. If it were suspended, or floated in something on water, it always came to rest in a definite way with its long axis in a north and south direction.[1] Up till this time, directions on the earth had to be found by the sun during the day, and by the stars at night. The particular stars seen in the sky, as you know, vary with the season of the year, some being seen only in summer and some only in winter. There are, however, some stars which are seen all the year round in the northern hemisphere, and there is one star which always keeps the same position relative to the earth. This is a star to be found in the constellation of the Little Bear, and is known as the Pole Star. The direction of the Pole Star is geographical north.

The disadvantage of finding one's way about on the sea by means of the stars is obvious, especially in these northerly climates, where so often there simply are not any stars to be seen. The result was that, during the Middle Ages, ships rarely went very far from the coast. The discovery of this property of the magnet of setting in a north and south direction opened up great possibilities in navigation, and by the time of Roger Bacon (1214–1284) it was in fairly common use.

[1] This was really a rediscovery; it had been known centuries before.

Roger Bacon in his book *Opus Majus* describes, in some detail, the properties of the magnet, or the 'lodestone' as it now began to be called; 'lode' being the Anglo-Saxon word for 'way.' He tells in particular of a compass made by one Petrus Peregrinus or Peter the Pilgrim. This was made by putting a magnet in a wooden cup which was floated on a bowl of water. This cup always

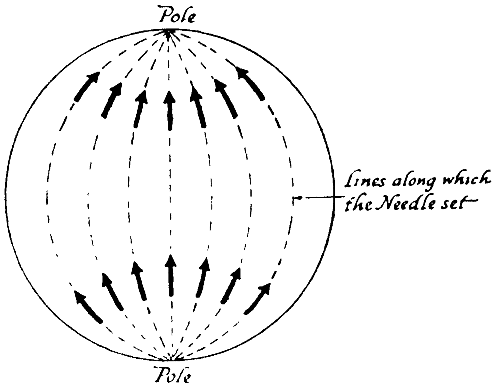


FIG. 13.—Showing how Peter Peregrinus found the poles of his spherical magnet

set so that the magnet inside it was in a north and south direction. In one of the notebooks of Leonardo da Vinci, that great artist-scientist about whom we have already heard, there is a drawing of just such a magnet, but with a compass card, showing eight points, mounted over the bowl as an improvement.

Peter Peregrinus.—It was the same Petrus Peregrinus who discovered and named the 'poles' of a magnet. He first had a piece of lodestone rounded into a globe. He then placed a needle on the globe and allowed it to 'set,' then he drew a line on the globe showing its direction. He moved the needle to another place, and again marked

its direction. This he repeated until he had a number of lines passing round the globe. Having done this, he found that the lines all crossed one another at two points on the globe which were at opposite ends of a diameter. He realised that these lines were just like the meridians (or lines of longitude) on the earth, which all pass through the North and South Poles. He therefore gave the name 'poles' to the two points on the lodestone where his lines crossed.

Dr William Gilbert.—During the two following centuries, except for the improvement of compasses and their increased use in navigation, the work of Peregrinus was not followed up. In Queen Elizabeth's reign, however, a great advance was made. A certain Dr William Gilbert of Colchester, later Physician to the Queen herself, became much interested in the lodestone and began to investigate its peculiar properties really scientifically.

He started off by rejecting all 'idle tales and trumpery' of its magic properties. Then he repeated the work of Peregrinus. He called the globe of lodestone a 'Terrella,' and pointed out that the 'poles' were definite points in the stone where its power or virtue was concentrated. He realised that these poles were of opposite nature to each other, and called the one which set towards the north the 'austral' pole and the other the 'boreal' pole. These names he took from the Latin words 'Auster,' the south wind, and 'Boreas,' the north wind. Nowadays they are called the north-seeking and south-seeking poles or, more simply but less correctly, the north and south poles of the magnet.

In his next experiment he floated a magnet, whose poles had been found, in a vessel on water. He then

took in his hand another magnet, whose poles were also known, and held its north-seeking pole towards the south-seeking pole of the floating magnet. The latter swung round towards the magnet in his hand, and followed it however it was moved. When, however, he held the south-seeking pole towards the south-seeking pole of the floating magnet it 'put the other to flight.' In this way he established the well-known law of attraction of unlike poles and repulsion of like poles, which is the first thing nowadays to be learnt about magnets.

Next he took a long-shaped magnet, which he assured himself had poles only at the ends, and broke it in half. He found that the broken ends now were poles, each being opposite in nature to the original one at the other end of the broken half.

Terrestrial Magnetism.—So much for the poles of the magnet. Now, Gilbert asked himself, why does a magnet always set itself in a north and south direction? The earlier answer to this question had been that the magnet was attracted towards the stars in the constellation of the Bear. Gilbert, however, from the first, thought that the explanation was to be found in the earth and not in the sky. He was a true scientist, however, and knew that he must put his ideas to the test and establish their truth by experiment. To do this he made use of his terrella, that ball of natural lodestone. He showed that a magnet on the surface of the terrella behaved in exactly the same way as a magnet on the surface of the earth—that is, it set itself in a direction pointing to the poles of the terrella. Therefore, he argued, the earth and the terrella must be similar in their natures. The earth must itself be a magnet.

The point on which he laid most stress was what he

called the 'magnetic dip.' He touched a needle with a piece of lodestone and so made it into an artificial magnet. This he suspended freely from its centre of gravity just above the terrella. It not only set itself in a north and south direction, but showed a definite dip towards the pole of the terrella to which it was nearest. Only if it were suspended midway between the two poles

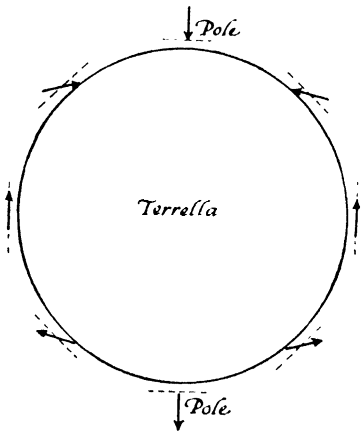


FIG. 14.—Showing the 'dip' of a magnet freely suspended above the surface of a terrella

did it take up a position parallel to the surface of the latter (see fig. 14). Moreover, Gilbert found that a magnet freely suspended above the surface of the earth always dipped towards the North Pole—so this further emphasised the likeness between the earth and terrella. He concluded, quite rightly as it was later shown, that in the southern hemisphere the magnet would dip towards the South Pole; while at the equator it should set in a horizontal position. The angle between the dipping magnet and a horizontal line through its mid-point is called the 'Angle of Dip.'

Magnetic Declination.—Quite soon after the introduction of the compass, navigators found that the needle did not point exactly to the pole star and did not, therefore, give the true north. More awkward still, the angle between the true north and the direction of the needle varied considerably according to the position on the

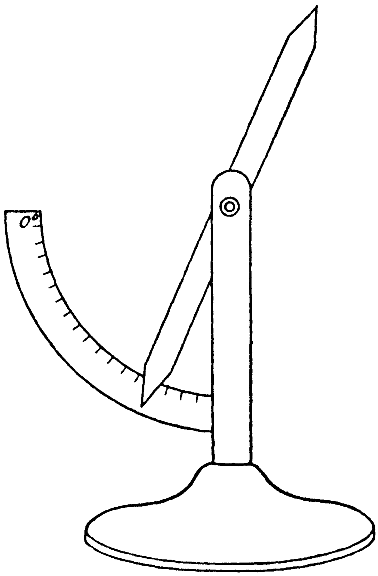


FIG. 15.—A simple dip needle

earth's surface. This angle is called the magnetic declination. The compass was, therefore, not such an accurate guide as had been hoped.

Although the declination varied so much, Gilbert thought that the angle of dip would always be the same at the same latitude and would always be zero at the equator. He, accordingly, devised an instrument known as the 'Dip Needle,' which he hoped could be used by navigators to tell the latitude. This consisted of a

magnetised needle, pivoted so that it could move in a vertical plane, instead of a horizontal one as in the case of a compass. When this vertical plane in which the dip-needle can move is in the magnetic meridian, the angle of dip can be read off on the circular scale (fig. 15).

Unfortunately it was found that the magnetic dip also varied slightly at the same latitude, and so, after all, Gilbert's dip-needle was not of much use to sailors. Nowadays both the magnetic dip and the magnetic declination have been determined at places all over the world, and every ship is provided with records of these. Maps have been drawn having lines on them joining up all the places of the same magnetic declination. In this way sailors are able to find their way accurately by the compass.

This study of the magnetism of the earth is always known as Terrestrial Magnetism.

Gilbert was also, naturally, interested in the property exhibited by rubbed amber of attracting light objects to itself. He discovered that amber was not the only substance which had this power of attraction. Other bodies such as glass and a number of gems behaved in a similar way when rubbed with wool, silk, or hair. He it was who first used the word 'electricity' to describe the strange effects produced in this way. He formed the term from the Greek word for amber, electron.

Gilbert divided substances up into two classes—electrics which could be 'electrified' by rubbing, and non-electrics. He found that electrified bodies lose their electricity if held near a flame or otherwise heated; and also that it was very difficult to electrify bodies on a damp day.

Gilbert laid sure foundations to the science of both

magnetism and electricity. In fact, in magnetism, apart from its connection with electricity, very little new has been discovered since his day. Advance in that science has been mainly along mathematical lines—that is, in discovering how to calculate exactly how big are the forces of attraction which a magnet exerts. We shall not attempt to deal with this part of the subject here.

II

During the seventeenth century little advance was made in either Electricity or Magnetism, apart from the gradual accumulation of knowledge concerning the magnetic variations in different parts of the earth. During the eighteenth century we find a great many people interested in the study of electricity.

Two Kinds of Electricity.—A Frenchman named *Dufay*, after carrying out a number of experiments, concluded that there were two kinds of electricity—one produced when glass is rubbed, and the other when amber is rubbed. He called the first 'vitreous' electricity and the second 'resinous'; since vitrum is the Latin for glass and amber is formed from the resin of certain pine trees. He came to this conclusion by discovering that two electrified bits of glass when suspended repelled each other. So did two electrified bits of amber. But a piece of electrified glass was attracted by a piece of electrified amber. Here was a rule about electrified bodies similar to that governing magnetic poles. It was quite easy after that to classify other electrified bodies by seeing whether they were attracted or repelled by an electrified rod of glass.

Storing Electricity.—We have already seen that Gilbert found it very difficult to make his experiments work on a

damp day, because he could not produce the electricity easily. A Dutch professor at Leyden conceived the idea of storing electricity to get over this difficulty. He thought that the electricity leaked away through the air; and to prevent this leakage he tried to arrange to have the charged body surrounded by a non-conductor—that is, one of Gilbert's electrics. This would hold the charge instead of letting it pass through it. To do this he suspended a bottle of water from a gun-barrel by means of a metal wire passing through the cork into the water. The gun-barrel was 'insulated' by suspending it by silk threads. (Silk is a non-conductor or an electric.) Next he charged the gun-barrel by an electrified glass body. Since the gun-barrel was made of metal which is a conductor, he thought that the charge would pass through into the water; here it would be protected by the surrounding glass flask which was a non-conductor. Then an astonishing thing occurred. He happened to touch the gun-barrel with one hand and the glass bottle with the other. Thereupon he got such a shock that he vowed he 'would not take another for the Kingdom of France.'

Other men, however, repeated the professor's experiment and turned it to good account. A certain Abbé Nollet amused the King of France by sending a 'shock' through a line of guards holding hands. You may imagine the effect! Later, he repeated this experiment with several hundred Carthusian Monks, who are said to have given a sudden spring altogether when contact was made. It was found that these shocks had no ill effects. In fact, a little later electric shocks, within limits of course, were actually prescribed by doctors for their tonic effect.

The Leyden Jar.—The original apparatus which had

produced the first shock on the Dutch professor became known as the 'Leyden jar.' Similar pieces of apparatus are still made and called by this name. A brass knob leading to the glass jar now replaces the gun-barrel, and the glass bottle is coated inside and out with tinfoil. If a metal wire is placed in contact with the outer tinfoil of a

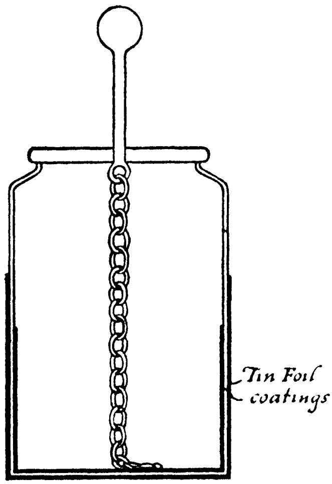
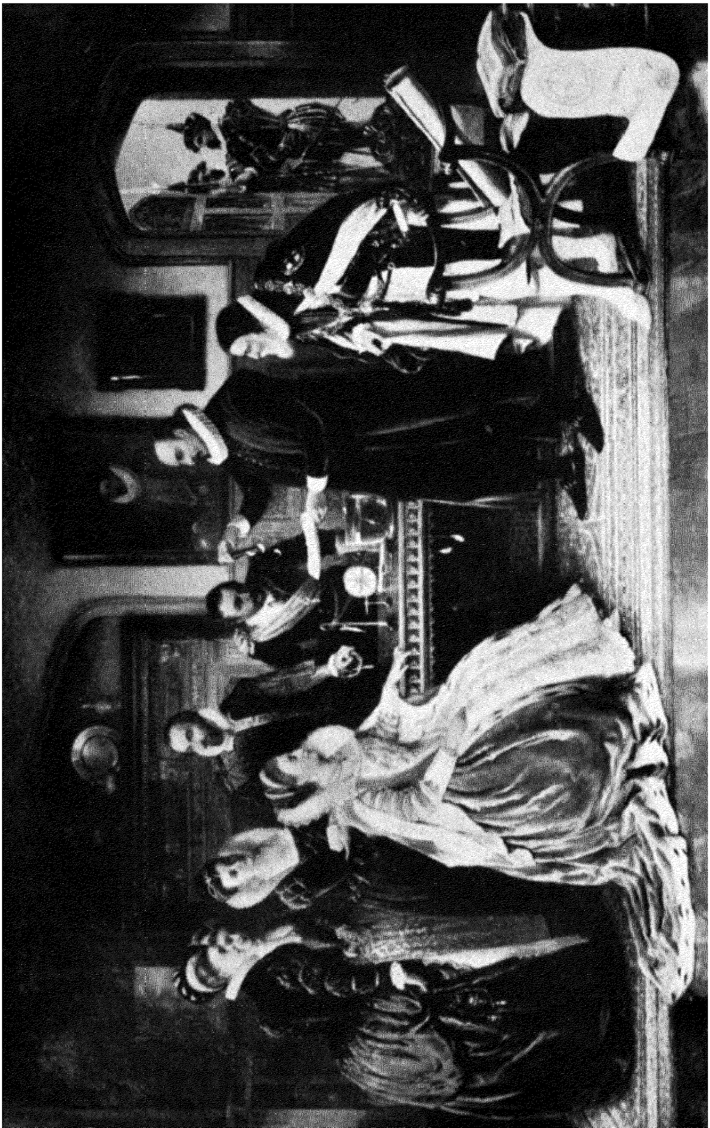


FIG. 16.—A modern form of Leyden jar

charged jar, and brought near to the brass knob, a bright spark passes from the wire to the knob with a loud crackle.

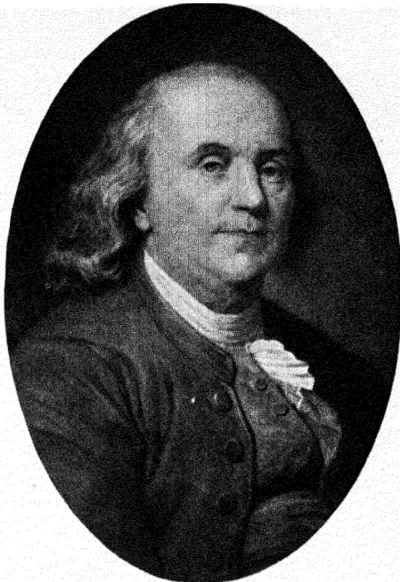
Electrical Machines.—For a good many years after Gilbert's time, electric charges were produced simply by rubbing pieces of amber, glass, or sulphur on material, such as the experimenter's coat or on his hand. During the seventeenth century a means of obtaining larger charges was devised. A ball of sulphur was mounted so that it could be spun round on its axis, and the hand was allowed to rub against the ball as it spun. In this way

PLATE XI

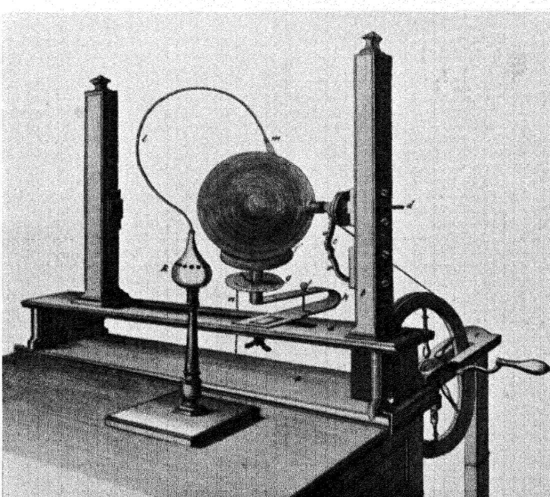


Dr Gilbert showing his Electrical Experiments to Queen Elizabeth and her Court

PLATE XII



Benjamin Franklin



Priestley's Electrical Machine

a charge was produced continuously by friction. This earliest electric machine was improved in various ways, the chief being to provide a driving wheel to turn the ball of sulphur or glass which rubbed against a fixed leather rubber. Both Priestley and Cavendish possessed electric machines of this type (Plate XII). Later machines, known as 'influence' machines, made use of the fact that one body may be electrified by another even when there is no contact. All modern electric machines are of this type. The best known is the Wimshurst machine.

Benjamin Franklin (1706–1790).—The greatest name of the eighteenth century, as far as the science of electricity is concerned, is that of Benjamin Franklin. He was an American—one of the very earliest of American scientists. His father had left England in search of religious freedom and settled in Boston, Massachusetts. Benjamin, after helping his father for a while in his candle and soap store, was apprenticed to a printer. Here he came into contact with books. Not contented with printing them he began to read them too, and began to acquire that wide knowledge and culture which was to make him stand out among the men of his time.

After some years he left Boston and opened a shop of his own in Philadelphia. His business thrived, and he began to take an active part in public affairs; on several occasions he visited England, sometimes on Government business. It was in this way that he met and became friendly with the English chemist, Dr Joseph Priestley.

Although now perhaps best known for his scientific achievements, his interest was not turned to electricity until he was forty years old and already a prominent man of his time in other ways. It was some experiments which he saw performed with the Leyden jar which started him

on this tack. Franklin's fame in the science of electricity rests on two things: first, on a new theory he put forward about the action of electricity; and secondly, on his demonstration that lightning is really a huge electric discharge or spark.

You will remember that Dufay had concluded from his experiments that there were two different kinds of electric fluid—vitreous and resinous. Franklin suggested that there was only one kind of fluid. Some bodies, however, had a deficiency of this fluid and others a superfluity. Those with extra fluid might be called positively charged, while those with less than the normal quantity might be called negatively charged.

The similarity between a flash of lightning and the sparks which can be drawn from an electrified body was obvious, but the proof that the lightning and sparks were identical in nature was not so easy. In 1752, however, Franklin succeeded in showing that this really was the case. He made a silk kite with a wood frame. To the top of this he fastened a pointed iron rod. The kite was fastened in the usual way to a length of twine at the end of which hung a key. This in turn was fastened to a piece of silk which Franklin held. His object was to charge the kite from a thunder-cloud. The pointed iron rod was used because it had been found out that points collected electricity across air much better than flat surfaces. The insulating silk attached to the key was, of course, to prevent Franklin getting an electric shock.

The first day that there was a good thunder-storm brewing Franklin and his son took the kite into a field and flew it towards the thunder-cloud overhead. At first nothing appeared to happen and the key remained uncharged. The rain coming on, however, wetted the

kite. Then Franklin saw that the thread fibres of the twine holding the kite were standing out in all directions, obviously electrified. He then put his knuckle to the key and was able to draw off a spark, and also to charge a Leyden jar from the key. In fact, the electricity taken from the key would do everything that the electricity taken from rubbed amber would do. It was clear that a flash of lightning was an electric discharge either between two charged clouds or between a cloud and the earth.

Franklin's work led directly to the invention of the modern lightning conductor. This consists of a long rod of metal ending with three points or forks projecting well above the highest point of the building. Its lower end is connected to a copper ribbon well buried in damp earth. A discharge from a cloud to the earth will obviously take the shortest path possible and will therefore strike the highest parts of buildings. The materials of which most buildings are made are very bad conductors of electricity, and the discharge therefore meets with a great deal of resistance, and much heat is developed. This causes sudden expansion, which wrecks the building and very often causes fire. A lightning conductor, however, attracts the electricity to its points and conveys it easily and quietly to the earth. It is most important that the conductor should be well buried in the earth, otherwise the foundation of the building will be wrecked.

Cavendish.—You will recall that in the chapter on Chemistry I said that in dealing with the early history of nearly every branch of science we should come upon the name of Cavendish. Well, here he is again, and once more we find him measuring. This time it is something rather more intangible than masses and volumes, for he is measuring forces. So far, investigators had been content

to distinguish between forces of attraction and forces of repulsion, and no attempt had been made to measure the forces or the charges which produced them. The only kind of force fully investigated at this time was the force of gravity—Newton had shown that this force varied directly as the product of the attracting masses and inversely as the square of the distance between them. Cavendish was able to show that an exactly similar law governed the attraction between charged bodies—that is to say, the force either of attraction or of repulsion between two charged bodies varies directly as the product of the *charges*, and inversely as the square of the distance between them.

Electrical Pressure or Potential.—Nowadays we are all very familiar with the term 'voltage.' You probably know that if there is a high voltage between two points a much greater current will flow than if there is only a low one. In a wireless set there is generally a high tension, or high voltage, battery and a low tension battery. These terms are usually used where an electric *current* (that is a continuous flow of electricity) is concerned, but they apply just as much to the momentary passage of electricity in the form of a spark.

In the days of Cavendish no one had as yet been able to produce a continuous current of electricity. Cavendish realised, however, that if two charged conductors were joined, electricity would probably flow from one to the other for a moment. He also realised that what decided which way the electricity would flow was not which body held the greatest amount of electricity, but which had the greatest 'degree of electrification.' You will understand what is meant by this if you think what determines which way water flows. Look at the diagram. A and B are two

vessels of water separated by a tap. There is obviously more water in A than in B, but if the tap is opened

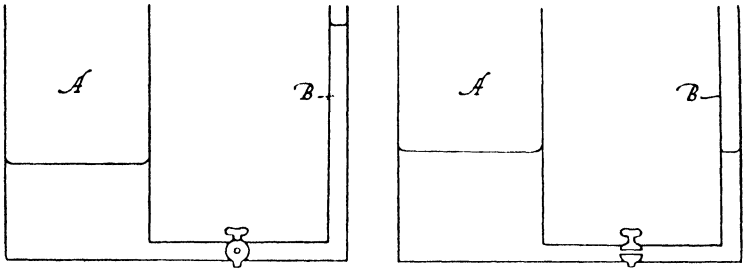


FIG. 17.—To illustrate pressure and capacity

water will flow from B to A. This is because the *pressure* of water in B, as shown by the level to which it reaches, is greater than in A. So water flows into A until the levels,

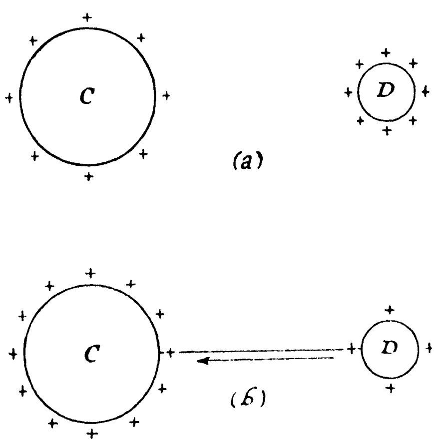


FIG. 18.—(*a*) Equal charges. Electrical pressure greatest on D. (*b*) Equal electrical pressure. Charge greatest on C

and therefore the pressures, are equal. Obviously, if the same amount of water is put into both A and B, the water in B will reach to a higher level or pressure than in A, because the capacity of A is the greater. It is just the

same with conductors holding electricity. If the same amount of charge is given to two conductors C and D, because C has the larger capacity for electricity, the degree of electrification, or 'electrical pressure,' will not be so high as on D. If the two conductors are joined, electricity will pass from D to C until the electrical pressures are equal. Now, although the electrical pressures are equal, C has more charge than D. Nowadays we talk of electrical potential rather than electrical pressure. It means exactly the same thing.

Electrical Capacity.—The electrical capacity of a conductor does not depend only on its size. In fact, it does not really depend upon its *size* at all but on its extent of surface, for the electricity of a charged body is to be found only on its surface. Electrical capacity does not depend on surface area alone, however; other things can alter the capacity. Suppose a conductor connected to the earth is brought close up to another insulated conductor which is charged. It is found that the electrical pressure, or potential, of this charged conductor becomes less, although no electricity has left it. To restore the potential more charge must be added. Another way of putting this is to say that the capacity of the charged conductor has been increased by bringing up the earthed conductor close, and more charge can be stored in it. If the two conductors are separated by glass, wax, sulphur, mica, or other insulator, instead of by air, the capacity is still further increased. Such an arrangement is called a condenser, which is an instrument used for storing electricity. Franklin made the first condenser, but the whole subject of potential and capacity was more fully investigated by Cavendish.

Condensers.—You are quite probably familiar with the

name condenser, as every wireless set contains one. A condenser consists of an insulated conductor separated by air, glass, or some other insulator from a conductor connected to earth. If the insulated conductor is charged, it will hold very much more electricity than if the earthed conductor were not there. Cavendish's condensers consisted of flat slabs of glass coated on both sides with tinfoil. These were the two conductors. The tinfoil on the lower side was, of course, the conductor connected to earth; and the upper tinfoil was the insulated one.

The Leyden jar is, of course, a condenser, as Cavendish realised. In the modern form the inner and outer coatings of the tinfoil on the glass bottle are the insulated and earthed conductors. The charge given to the knob is passed on by the chain to the inner coating.

Finally, Cavendish found that all so-called 'conductors' did not allow electricity to pass through them with equal ease. Moreover, he devised an experiment whereby he could measure the relative conducting powers of different materials. We have already seen that if a Leyden jar be discharged by touching the knob with one hand and the outside with the other, a powerful shock is experienced. Instead of touching the knob directly with one hand, Cavendish connected to it one end of a piece of the substance whose conductivity was to be investigated. He then held the other end in one hand and discharged the jar by touching the outside. In comparing conductivities he adjusted the lengths of the material used until he judged that the same degree of shock was experienced in each case. The ratio of these lengths then gave the relative conducting power of the materials.

In this way Cavendish found that 'Iron wire conducts

four hundred million times better than rain or distilled water, and sea-water conducts one hundred times better than rain water."

III

The Electric Current.—The electrical machines and condensers possessed by Cavendish and other experimenters were capable of providing quite a large store of electricity and of giving a powerful spark when discharged. The effect of the spark was, however, only momentary. Apart from its use in some chemical experiments already described, it was of little practical value, although an endless source of entertainment. In 1780, however, a discovery was made, the consequences of which were to bring about the harnessing of electricity to the practical requirements of modern civilisation.

Galvani (1737–1789).—The discovery was made by an Italian Professor of Anatomy, Luigi Galvani. He had dissected a frog and left it pinned out on a table near to an electrical machine. A student happened to touch one of the inner nerves of the frog with the blade of his scalpel (or dissecting knife). To his surprise he observed that the frog's legs gave a sudden kick. Now the sudden contraction of muscles when they receive an electric shock was well known, and the kick of the frog's legs was at once attributed to such an electrical cause. Galvani, at first, naturally put the occurrence down to the presence of the electrical machine. He determined, however, to investigate further. He prepared a number of frogs and fixed them by means of brass hooks to an iron fence in his garden. Knowing that lightning was an electric discharge, he wished to see whether the same kick would occur during a thunder-storm. Before any thunder-

storm occurred he made an important discovery while he was putting up the frogs. In fixing the brass hooks to the iron fence he found that, if the legs of the frogs touched the iron fence, they gave a convulsive twitch. This always happened whatever the state of the weather. He then prepared more frogs, and fixed them by means of brass hooks to an iron plate. He did this indoors, so that any electrical disturbance *outside* would not affect the result. On pressing the brass hook against the iron plate the same kick was observed. Evidently the cause of the kick was the contact of the two different metals, brass and iron, with the frog's nerves and muscles.

The explanation which Galvani gave of this unexpected occurrence was that there was stored in the tissues of the frog a quantity of electricity. This he called 'animal electricity.' The contact of the metals with each other and with the animal discharged this electricity, so causing the muscles of the frog to contract suddenly.

Volta (1745–1827).—There was another professor in Italy who did not agree with this explanation given by Galvani. He was Alessandro Volta, Professor of Natural Philosophy in the University of Pavia. The explanation he gave instead proved to be the right one and led to further very fruitful results. Because of this, Galvani, in spite of his careful investigations, lost a great deal of credit for the important results which followed his original discoveries.

Volta maintained that the electricity did not come from the frog, but from the two different metals in contact. The part played by the frog was simply to form a path. He tried joining the two metals by other things, such as blotting-paper soaked in brine, and found he could still

get a discharge of electricity. He got a much better effect by using more than one pair of metals, and so made his famous Volta's Pile, using zinc and copper as the two metals.

Volta's Pile.—The 'Pile' consisted of plates of zinc separated from plates of copper by pieces of cardboard soaked in dilute acid. The discs were placed in the order, zinc cardboard copper, zinc cardboard copper, etc. In this way a zinc plate was left free at one end, and a copper plate at the other. By bringing a wire connected to one end plate near to the other a small spark could be drawn off. The difference between this and the Leyden jar was important. In the latter, the spark was big, but once the spark had passed no more electricity could be obtained from the jar. With Volta's pile, on the other hand, an indefinite number of small sparks could be drawn off. In fact, a continuous source of electricity had been produced. The quiet flow of this electricity along the wire was henceforth called an *electric current.*

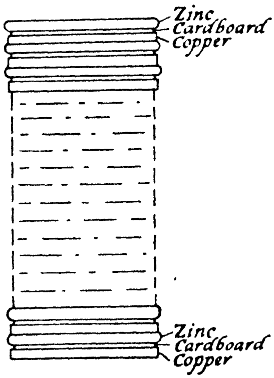


FIG. 19.—Arrangement of elements in Volta's pile

The Simple Cell.—Volta's next step was to make what is now known as a simple cell. Instead of using discs of copper and zinc he took a strip of each metal and dipped the strips into a cup of dilute acid. By joining up a number of the cells by wires from the copper of one cell to the zinc of the next he was able to obtain quite a strong current. Such an arrangement of cells is called a battery. The simple cell is never used as a practical source of

current now, as there are certain grave disadvantages attached to it. All the modern types of primary cells, however, are really only elaborations of this original cell. This does not apply to the well-known accumulator which, of course, has first to be charged before it will yield a current.

The Electric Current and Chemical Decomposition.—We have already seen what a tremendous help this invention of Volta was to Davy in decomposing the caustic alkalis and so finding a number of new elements. Davy's successor at the Royal Institution, Michael Faraday, investigated still further the action of an electric current in decomposing chemical substances in solution. These investigations of Faraday have had very far-reaching results in two directions. In the first place, they helped later chemists to explain the true nature of chemical action. It is now known that in nearly all cases chemical action between substances is due to the attraction of opposite charges of electricity. In the second place, these investigations laid the foundations of the very important modern industry of electro-plating. That is all we can say about that part of Faraday's work here. There is a very great deal more to say about Faraday and his work on electricity, but we must come back to him again when we have dealt with the work of one or two more of Davy's contemporaries.

Oersted (1777–1851).—The first of these was a Dane, Hans Christian Oersted. He is important, because it was he who first was able to show the close connection between magnetism and electricity. This discovery was not an accident. It seemed to him extremely probable that such a connection did exist, and he spent many years trying to prove that it did. The successful experiment

was really very simple. He held a wire carrying an electric current over a pivoted magnetic needle, and parallel to it. Immediately the magnet was deflected. The direction of the current was then reversed in the wire and the needle was then deflected in the opposite direction. Other experiments had failed because hitherto the needle had been placed at right angles to the wire instead of parallel to it.

André Marie Ampère.—This discovery of Oersted was immediately investigated further by a Frenchman named Ampère. He brought mathematics to his aid, and was able to measure the amount of force which caused the needle to turn through a given angle. As this force was due to the current flowing in the wire, this formed a good way of measuring the strength of the current. The ordinary units by which we measure a current to-day are called amperes or 'amps' after this man. As a matter of fact, a great many electrical terms are derived from the names of great experimenters in electricity. An instrument for detecting a current is called a galvanometer, from Galvani; or, if it is to measure the current in amperes, it is called an ammeter. The earliest galvanometer consisted of a coil of wire with a magnetic needle pivoted or suspended at the centre of the coil. When a current flowed through the wire the needle was deflected.

The Electric Telegraph.—Ampère was the first man to suggest the possibility of the electric telegraph. This originally consisted of a galvanometer at the distant receiving station, connected by two wires to a battery of cells at the sending station. A current sent in one direction deflected the needle of the galvanometer one way, and a current in the other direction reversed the deflection. A man named Morse invented his famous 'Morse Code.'

Taking a deflection in one direction to mean a dash and in the other a dot, it was possible to transmit messages by sending pulses of current along the wires to the galvanometer. Later it was found that only one wire between the stations was needed, as if the galvanometer and one terminal of the battery were each connected to the ground, the earth brought the current back.

Ohm (1789–1854).—You will remember that Cavendish first introduced the idea of potential, or electrical pressure in connection with his condensers. The bigger the difference of potential between the two plates of the condenser, the bigger the spark which can be got from them. In the same way, the bigger the difference of potential between the two terminals of a battery the greater is the strength of the current which flows through the 'circuit' connecting these terminals. A German contemporary of Ampère and Oersted, named Georg Simon Ohm, showed that the current produced was directly proportional to the potential difference between the terminals, providing that the path of the current was not altered. Ohm also recognised that it was the constant potential difference maintained between the terminals of the cell which was the driving force of the current in the circuit. He called the potential difference the Electromotive Force.

Ohm's Law.—The actual current produced by any constant electromotive force depends upon the path along which it flows. The ratio of the electromotive force to the current produced Ohm called the 'Resistance' of the circuit. The bigger the resistance the less current is produced. '*Ohm's Law*,' as it is now called, is a very important one, as it enables us to calculate just how much current we shall get if we apply a known electromotive force to a circuit of which we know the resistance, or, on

the other hand, if we read the current flowing by means of an ammeter, we can calculate the resistance of a circuit. As the heating power of a current depends upon both the current and the resistance it is very important to know the value of both quantities.

Ohm's Law is usually written in the form:

$$\frac{\text{Electromotive Force (E)}}{\text{Current (C)}} = \text{Resistance (R)},$$

$$\frac{E}{C} = R.$$

IV

Michael Faraday (1791–1867).—Having dealt with the very important work of Oersted, Ampère, and Ohm we can now turn to that great scientist and great man, Michael Faraday. In 1931 there was held in London's biggest hall, the Albert Hall, a great electrical exhibition known as the Faraday Exhibition. In the very centre of the hall was a bust of Faraday and a stand bearing his original notebooks. In a ring round this were set up the actual apparatus used by Faraday in his original experiments, many of which could actually be seen performed. Out from this inner ring radiated in all directions, completely filling the vast hall, models of the inventions and discoveries of which one of his experiments had been the starting-point. Perhaps the most striking thing of all was to go from the outer ring where were shown the intricate wonders of twentieth-century elaboration, back to the centre and starting-point of it all; to look on the simple bits of apparatus and to read Faraday's simple and clear explanation of the experiments which had had such far-reaching results.

Who was Michael Faraday? He was the son of a blacksmith, and at the age of thirteen was delivering papers for a bookseller in London. Later he became apprenticed to the bookseller and so came into close contact with the world of books. From the first it was scientific books which he devoured. He spent his meagre pocket-money in making home-made apparatus to carry out for himself the experiments about which he read. His first voltaic pile was made from halfpennies and discs of zinc! During this time Davy was giving his lectures at the Royal Institution. To some of these Faraday went. His longing to devote himself entirely to science was increased tenfold by these lectures. Finally he made up his mind to a bold course of action. He had taken careful notes of the lectures, and these he sent to Davy telling him of his great desire and asking whether an opportunity could be given him of realising it. Perhaps the most valuable contribution that Davy made to science was his kindly reception of this letter and his action in taking Faraday into his laboratory as his assistant. So with two rooms in the Royal Institution and a salary of twenty-five shillings per week Faraday began his long and fruitful career.

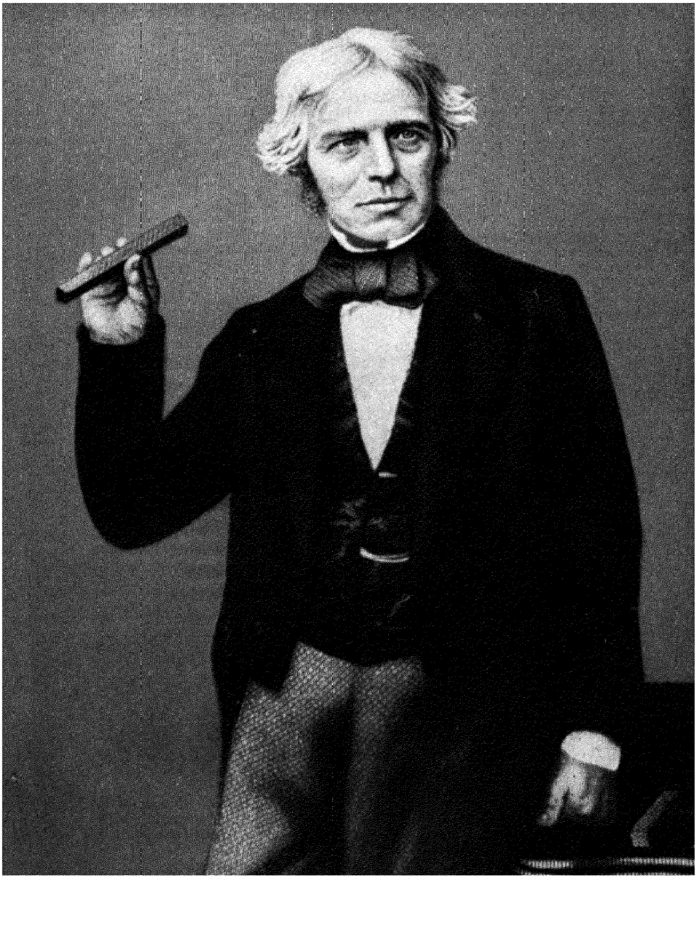
Not immediately did success and honours come. There had been no preliminary college career for Faraday, nor even a grammar-school education. He had to start from the very beginning. At that time Sir Humphry Davy's star filled the horizon of the scientific world, at any rate in London, and Faraday was only a poor laboratory assistant when, in Faraday's first year at the Royal Institution, Davy went on his famous European tour. Faraday accompanied him as his assistant and valet. The opportunity was a golden one, for in this way Faraday

met personally almost all the famous scientists then working on the Continent.

On his return to England Faraday continued steadily and thoroughly to lay those firm foundations on which the great edifice of his later work was built. Unlike the majority of scientists of his day, mathematics was of little use to him. This was largely owing, of course, to lack of training, but undoubtedly also to lack of aptitude. In its place, however, he had what one might call a natural intuition for selecting, out of a mass of facts, just those that were important to the matter in hand. In short, he was a scientific genius. Gradually this genius, in face of the many obstacles, won its way and placed Faraday at the forefront. At the Royal Institution, on Davy's retirement, he stepped into the latter's place and became also Director of the Laboratory. This position he held in spite of other offers until failing health made it necessary for him to retire and end his days at Hampton Court; perhaps the most worthy of honour and gratitude of all Britain's 'state pensioners.' Both in England and abroad the name of Michael Faraday was loved and honoured, but he would accept no material tribute. He lived and died a poor man.

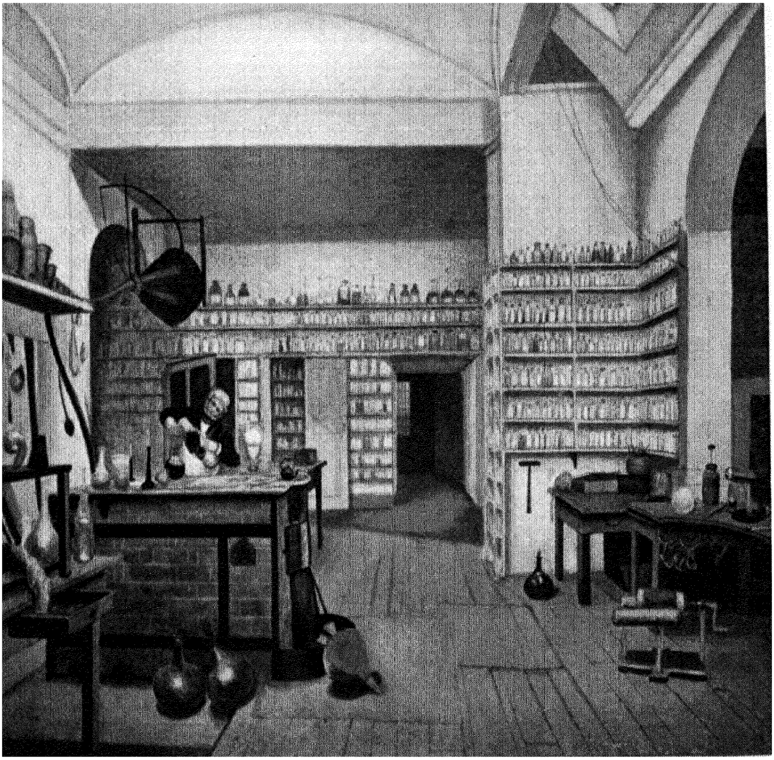
Faraday's appointment at the Royal Institution was a chemical one in the first place, and his early work was all on chemical lines. Valuable as it was it cannot here have special mention. All this time, however, he was in daily touch with men working in every branch of science, and he was fully aware of the problems with which they were occupied. Faraday's active mind busied itself also with these problems, and it was in this way that he was led to the study of electricity and to the discovery which gained him such world-wide fame.

PLATE XIII



Michael Faraday

PLATE XIV



Faraday in his Laboratory at the Royal Institution

(By permission of the Royal Institution)

Electro-Magnetic Induction.—Oersted's experiment had shown that there was a very intimate connection between magnetism and electricity. The following facts were now established definitely:—

(1) A magnet can induce or give rise to magnetism in an adjacent iron body.

(2) An electric charge produced by friction on one body can induce electricity in another body.

(3) An electric current gives rise to magnetism.

Certain questions presented themselves at once to Faraday. Since an electric current gives rise to magnetic effects, cannot magnetism give rise to a current? Cannot a current of electricity flowing in one wire induce a current in a neighbouring wire?

These were the questions which Faraday set himself to answer; and the experiments which finally gave him the answers were all to be seen, just as he had them set up, at the Faraday Exhibition in 1931. I am going to describe the experiments to you as if they were successful straight away, in order that you may understand them more easily. Actually there were a good many experiments which were not successful. Faraday did not make his great discovery by luck, but by patient and careful research.

For the final successful experiment Faraday made a long coil or helix of copper wire, the ends of which were connected to a galvanometer which would register any current produced in the wire. Into this he placed quickly the whole length of a bar-magnet, and then pulled it out again.

As the magnet moved into the coil of wire the needle of the galvanometer moved, registering a current in the coil of wire. While the magnet remained still in the coil

no current was registered. When the magnet was pulled out the galvanometer needle again moved, but in the opposite direction, thus registering a reverse current in the coil.

The net result of this experiment is that when a magnet *moves* near a wire forming a closed circuit a current flows in the wire. The direction of the current depends on the direction in which the North Pole of the magnet

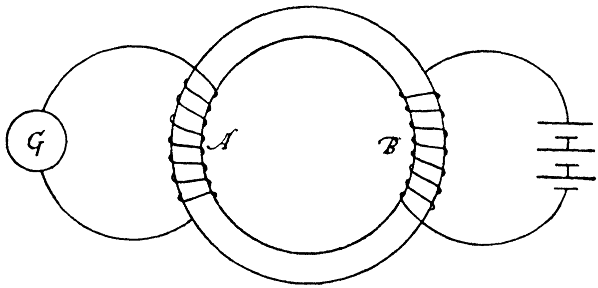


FIG. 20.—Illustrating Faraday's experiment on induced currents

moves. If the magnet remains *still* near the circuit there is no effect.

Next Faraday turned his attention to the second question: Can one current induce another? For this he took a heavy iron ring. On one part he wound a great many feet of copper wire (A) connecting the ends to a galvanometer. On the opposite side he wound another piece of wire (B) and connected the ends to a battery. So long as a steady current flowed in B no movement occurred in the galvanometer needle, showing that no current had been induced in A. Just as the wire from B was connected to the battery, however, there was a sudden movement of the galvanometer needle joined to A. A movement of the needle in the opposite direction occurred

when the B was disconnected from the battery. From the experiment, therefore, Faraday concluded that a steady current will not induce another current, but a momentary 'induced' current is formed on 'making' or 'breaking' the circuit.

Now let us see how Faraday explained these results. The power possessed by magnets and electrified bodies

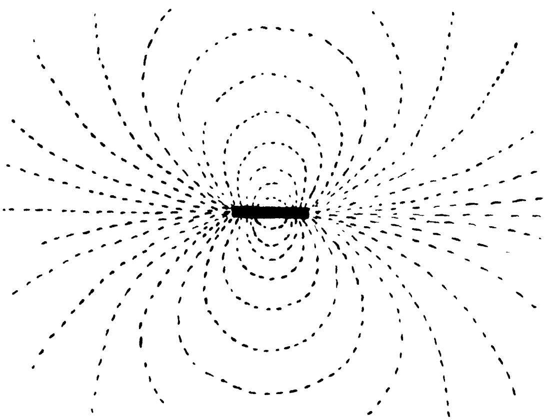


FIG. 21.—Showing Faraday's 'Lines of Force'

of being able to attract 'at a distance' had always worried scientists. The general explanation held during the seventeenth and eighteenth centuries had been that some subtle fluid issued from or entered the bodies and the attracted bodies were caught up in this stream. Faraday now put forward a new explanation of magnetic and electric force which was such a fruitful one that it is now universally adopted. It was a well-known fact in his time that iron filings in the neighbourhood of a magnet set themselves along definite curved lines stretching from one pole of a magnet to the other. Faraday suggested that the whole of the space surrounding a

magnet was in a state of strain, just as a piece of cloth stretched tightly over a frame is strained. He said that the forces producing this strain acted along definite curved lines which he called lines of magnetic force. These lines were shown very clearly by the iron filings which were pulled into the direction of the force. Where the magnetic force was very strong, the lines were crowded together, as, for instance, near the North and South Poles. Where the force was weaker fewer lines existed. He showed that these lines tended to crowd into iron. If, therefore, a piece of iron were placed near a magnet, there would be a great number of magnetic lines of force passing between the magnet and the piece of iron. Faraday compared these lines to stretched elastic strings, always trying to contract. If the piece of iron were free to move, or very light, as in the case of iron filings, the lines would contract and the iron would move towards the magnet.

Faraday used this new conception of the 'field of force' surrounding a magnet to make one explanation cover both of his experiments on induced currents. Let us think first of the experiment in which he pushed the bar-magnet into the coil of wire and then pulled it out again. Try to imagine the magnet with its lines of magnetic force filling all the space immediately round it. Before the magnet was brought up to the coil none of the lines of force threaded the latter. As it approached the coil, however, more and more lines crowded in, until a maximum was reached when the magnet was right inside. When the magnet was pulled out the number of lines diminished from this maximum until once again there were none threading the coil. Now it was only when the number of lines of force was *changing* that a current was induced in the wire of the coil.

Now let us turn to the second experiment where the coils A and B were wound on the iron ring, A being connected to a galvanometer and B to a battery. Remember that Oersted had shown that a magnetic field always is present when an electric current flows. Faraday showed that in this case the lines of force ran in a series of widening circles round the wire in which the current was

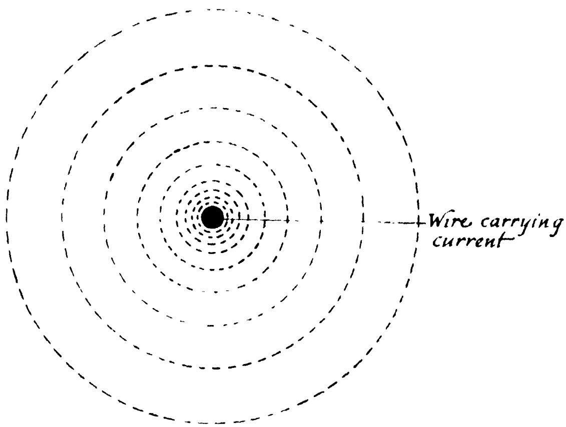


FIG. 22.—Showing lines of force round wire carrying current

flowing. When, therefore, a current flowed in the wire B, circles of magnetic force would 'thread' the coil, and the outer ones would also thread the coil A. When the current was steady the number of lines of force threading A would also be steady. But when B was first connected to the battery both the current and its accompanying lines of force had to grow from zero to their maximum value. This happened very rapidly, but while it was happening the galvanometer attached to A showed that a current was induced in B. Similarly, when the battery was disconnected from B, both the current and the magnetic field diminished suddenly to zero.

During the change another induced current flowed. Both experiments, then, really gave the same result. Whenever the lines of magnetic force cutting a wire which is part of a closed circuit are changing, a current is induced in the wire. If the lines are increasing, the current is in one direction; if they are decreasing then the current is reversed. It is immaterial, of course, how the changing magnetic field is produced. It may be either by a magnet or by another current.

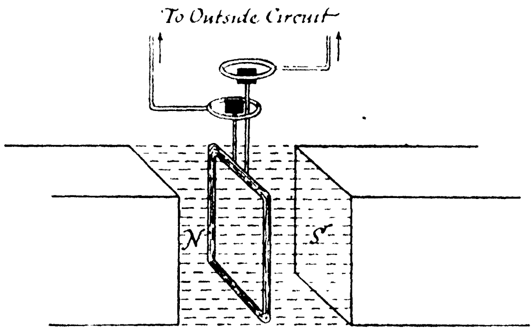


FIG. 23.—Diagram to show principle of the dynamo

The Dynamo.—It was not long before the practical results of this discovery were realised and put to use in the invention of the dynamo and the electric motor. With these inventions was ushered in the 'Electric Age' in which we live. Briefly the dynamo is a device to keep coils of wire continually cutting lines of magnetic force. In this way a perpetual induced current is formed in the coil and led off and used in any way which may be desired. In its simplest form a coil of wire is revolved between the poles of a large horse-shoe magnet, so that the coil is alternately at right angles to, and parallel to, the lines of force passing between the

poles of the magnet. This means that the number of lines 'threading' the coil is a maximum when the coil is at right angles and a minimum when parallel to the lines of force. In this way the direction of the current is continually reversed and what is known as an 'alternating current' is formed. Formerly a device to change this to a 'direct' current was employed, but this has now been found to be unnecessary and is not so much used.

You may wonder why the dynamo is better than a battery for producing an electric current. The answer is that one dynamo can do the work of a very great number of cells. Such a battery of cells is unwieldy and expensive. The materials also are constantly being used up. Once a dynamo is made, apart from a certain amount of wear and tear, it is more or less permanent. The chief expense is in the source of energy to turn the coil. The best and cheapest source is water-power, and that is why mountainous countries such as Scandinavia and Switzerland have such splendid electric services. Other countries use chiefly steam-power, with coal or oil as fuel.

The Electric Motor.—The electric motor is similar to the dynamo in construction. Instead, however, of the coil being turned between the poles of the magnet to produce the current, a current is sent through the coil. The attraction between the poles of the magnet and the magnetic field due to the current then makes the coil rotate; and if the necessary gear is attached to the coil it can be made to do work. It cannot be expected that the working of an electric motor can be fully understood from this description, but an explanation can be found in any text-book on electricity.

It is quite impossible to enumerate the many inventions which followed on Faraday's discovery. The telephone

is just one example. During the rest of the nineteenth century one invention followed another.

James Clerk Maxwell (1831–1879).—Just one more name we must mention is that of James Clerk Maxwell, for, in a way, he may be said to have rounded off Faraday's work. Faraday, we have seen, was no mathematician. The proofs he brought in support of his theories were experimental proofs and were never supported by mathematics. Now a scientist dearly loves mathematical proofs, and indeed they are very useful, not only as confirmation of experiment but in predicting new experimental results.

Maxwell was a very gifted Professor of Mathematics. He was a younger man than Faraday, being only thirty-six when Faraday died an old man of seventy-six. He was lucky enough to know Faraday personally, however, and was especially interested in the latter's idea of lines of force. His great work was to show mathematically that Faraday was right in this idea. He then went on to show, all by his mathematical calculations, that light, plain common-or-garden light, was what he termed an 'electro-magnetic' phenomenon. What he meant by that was that the particular disturbance in the ether which, when it hits our eyes, enables us to 'see,' really consists of a succession of pulses of a force which is of the same kind as the force causing the strain which we call a magnetic field. That is all very well, it may be said, if one happens to be interested in that kind of thing, but it really does not mean much to anyone who is not a mathematician. That is quite true; but by those same abstruse mathematical calculations, Maxwell predicted the formation of 'wireless waves.' This set a man named Hertz looking for them; and he found them! It must be

admitted the finding of wireless waves is of considerable interest to a great many people. But we will talk of these again later.

Maxwell died in 1879, more than fifty years ago. Needless to say, discoveries concerning electricity have occurred since then. They are, however, of quite a different nature from those dealt with in this chapter, and link up more closely with present-day work which is still going on. We will, therefore, leave them till the last chapter of all.

CHAPTER XII

The Development of Power

I

Power in the Ancient World.—The pyramids of Egypt, built some four thousand years ago, are monuments of engineering skill, and call forth the admiration of all who gaze upon them. The power used to raise those huge masses of stone to the top of the pyramid—a tremendous height—must have been enormous. Yet it was all human power, and as far as we know, unaided by any mechanical device, with the possible exception of the lever. Armies of slaves, harnessed by ropes to the stone blocks, used their concerted efforts to move them; and the time taken to hew out one block and bring it to its final position in the building must have been very considerable.

There is no need to remind you of the state of things to-day. Mechanical power is everywhere used for moving, transporting, and lifting materials of all kinds. The actual muscular power of humans or animals is used less and less, and there are few operations for which no machine has ever been devised. The story of how this change came about is the subject of this chapter.

Force.—We must first be quite clear what we mean by a machine. The dictionary defines a machine as 'an instrument of force,' which brings in another word to be clearly understood. The idea behind the expression to 'use physical force' will make a very good starting-place.

Now, if you use force on something, unless you are

resisted, motion of some kind will follow, either of you yourself or of the object on which force is exerted, or very probably of both. Suppose now you want to lift a heavy sack two or three feet. The sack is heavy because there is a very strong force (of gravity) pulling it towards the centre of the earth. To lift that sack you must exert on it a force which is greater than the force of gravity. If you are not very strong you may not have sufficient force at your command to do this. There are various ways, however, in which you could contrive to make such as you have enough.

Machines.—For instance, you might use one or more pulleys. A pulley is a small grooved wheel which turns very smoothly on its axle. It is generally fixed in a frame which can be fastened to the ceiling or to some support. Suppose, now, you fasten a rope to the sack, pass the rope over the pulley, and then pull the rope. You might now be able to lift the sack. You would, as a matter of fact, have to exert just as much force as the weight of the sack, but you could now use the weight of your body to help you. If you had two pulleys, arranged as shown, you need only use half the force; or with six, only one-sixth of the force. A set of pulleys, therefore, is a machine which allows you to overcome one force by using a smaller one.

The lever is another device of the same sort. Suppose a tin, such as a treacle tin, has its lid jammed in firmly, so that you cannot get it open by pulling with your fingers. If a spanner, or a knife, is put under the rim of the lid and the other end pressed down, it is possible to 'lever,' or prise, it open. The simplest kind of lever is a straight rod which can hinge about some definite point called the fulcrum. In the case above, the spanner hinged on the

edge of the tin as the fulcrum. You probably know quite well that the longer the spanner you use the less force will you have to exert on the end. There are many different kinds of levers. A see-saw, or a weighing

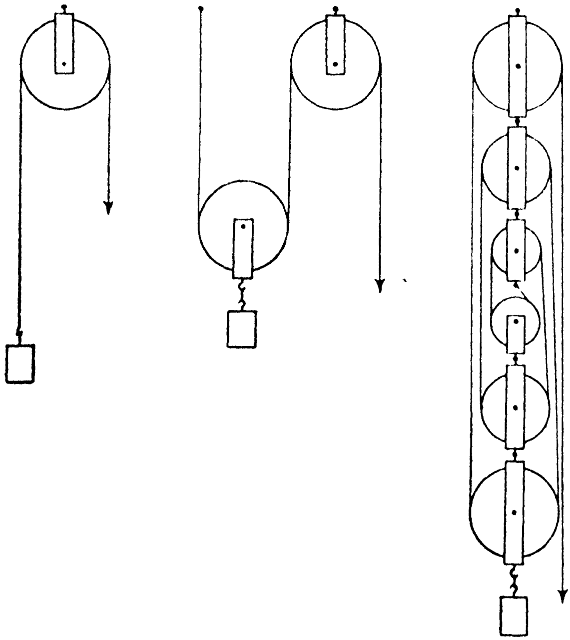


FIG. 24.—Showing various arrangements of pulleys to reduce the force needed to lift a weight

machine, are simple types where the fulcrum is in the middle. There are many other more complicated kinds, but the same rule applies to them all. If the force is exerted at a point which is farther away from the fulcrum than is the load, then a smaller force is needed to lift or move the latter. The greater the distance of the force from the fulcrum, compared with the distance of the load from the fulcrum, the smaller the force needed.

Archimedes (287–212 B.C.).—It was Archimedes who first used pulleys and levers as mechanical aids to human force. He used these devices in helping the men of Syracuse to move their ships and tackle; and we have seen, in Part I, how he used many mechanical aids in the defence of the town against the Romans.

Leonardo da Vinci.—After Archimedes, the next man we hear of as interesting himself in these devices was Leonardo da Vinci. In the story of his life we read that he constructed a machine to raise the Holy Nail, which was a prized possession of Milan, to its position above the altar of the great cathedral which was being built. His notebooks are full of plans for similar devices.

The next advance was to find a machine which would act as a substitute for human power. This accomplished, pulleys and levers would still be used as aids to the new force. Before coming directly to these new machines, there is a long story to tell of discoveries which led ultimately to their invention, although in so doing we may seem to wander rather far afield.

The Suction Pump.—The Duke of Tuscany to whom Galileo was appointed mathematician and philosopher after he had left Padua wished to have a new well made. Accordingly the well was dug, and it had to be a deep one, forty feet down to the water. The next thing was to fit a pump to bring the water to the surface of the earth. Now pumps were known and used in the time of Aristotle. The pump in use at this time consisted of a long tube, the length of the well, dipping into the water at the bottom. At the top it opened into a wider cylinder (C) by means of a little door or valve (B) which would only open upwards. Fitting into the cylinder was a disc or piston (P) which could just move

up and down when worked by a rod. In the piston was another valve (A) which also would only open upwards.

To work the pump, the piston was moved first down then up, and the movement repeated until an upward movement brought up water on top of the piston. Let us see how this came about. The downward stroke of the piston would squeeze out the air beneath it in the cylinder. On pulling up the piston, therefore, an empty space or vacuum would tend to be formed; but instead of this happening, the air from the pipe was sucked up into the cylinder through the valve (B), while some water was sucked into the pipe. The next downward stroke of the piston squeezed out this new lot of air, and on the upward stroke still more water was sucked up. Finally, water was sucked into the cylinder. On the following downward stroke it was the water which was squeezed through the valve (A), which then closed under the weight of the water so that on the upward stroke the water was carried up with the piston and came out of the mouth of the pump.

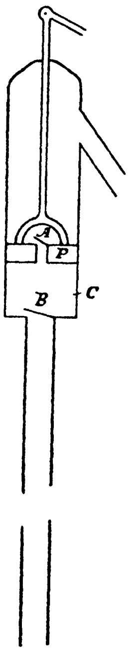


FIG. 25. — A suction pump

The Greek philosophers had been almost unanimous in thinking that a vacuum—an entirely empty space—could not exist. Whenever it seemed likely that one might be formed, something would always move in to fill up the space. This conclusion of theirs was generally expressed by the phrase 'Nature abhors a vacuum.' In the case of the pump, when the piston is raised after squeezing all the air out from under it, there would

obviously seem to be a possibility of the formation of a vacuum. Instead, however, the water and the air from the pipe push up through (B), and take the place of air squeezed out, 'because,' as the old philosophers said, 'Nature abhors a vacuum.'

Now when the pump over the Duke of Tuscany's well was set to work a quite unprecedented thing occurred. No water could be raised to the surface. The water refused to rise higher than thirty-four feet. (The well, you remember, was forty feet deep.) Nothing the men could do would get it beyond this height. Galileo was called in to see if he could offer any suggestion, but even he could not see the reason for the failure of the pump. All he could say was that evidently Nature's abhorrence of a vacuum did not extend beyond thirty-four feet! This problem of the pump was one which Galileo himself never solved.

Evangelista Torricelli (1608–1647).—The man who did find the solution, however, was one of his pupils, Evangelista Torricelli. He pondered over it for a long time and finally arrived at what he thought was the true explanation. To test his theory he devised an experiment in which he determined to use mercury instead of water. Mercury is much heavier than water, and so occupies less space, weight for weight. He needed for his experiment very thick glass tubes, and these took a long time to make. The tubes were about a yard long and closed at one end. He filled the tube with mercury, and then closed the open end with his thumb and inverted the tube into a basin of mercury. The mercury began to run out of the tube, but when the column of liquid was thirty inches high no more ran out and it remained quite steady.

This was what Torricelli had expected to happen. He

said that the space above the top of the mercury in the tube was a vacuum. The column of mercury was held up in the tube by the pressure of the air outside pressing on the surface of the mercury in the basin. He calculated that a column of mercury thirty inches high weighed the same as a column of water (of the same thickness) which was thirty-four feet high. The pump failed to work because the air could not hold up a column of water longer than thirty-four feet.

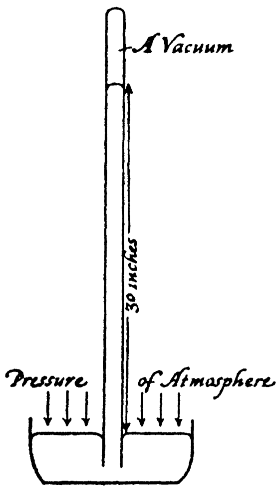
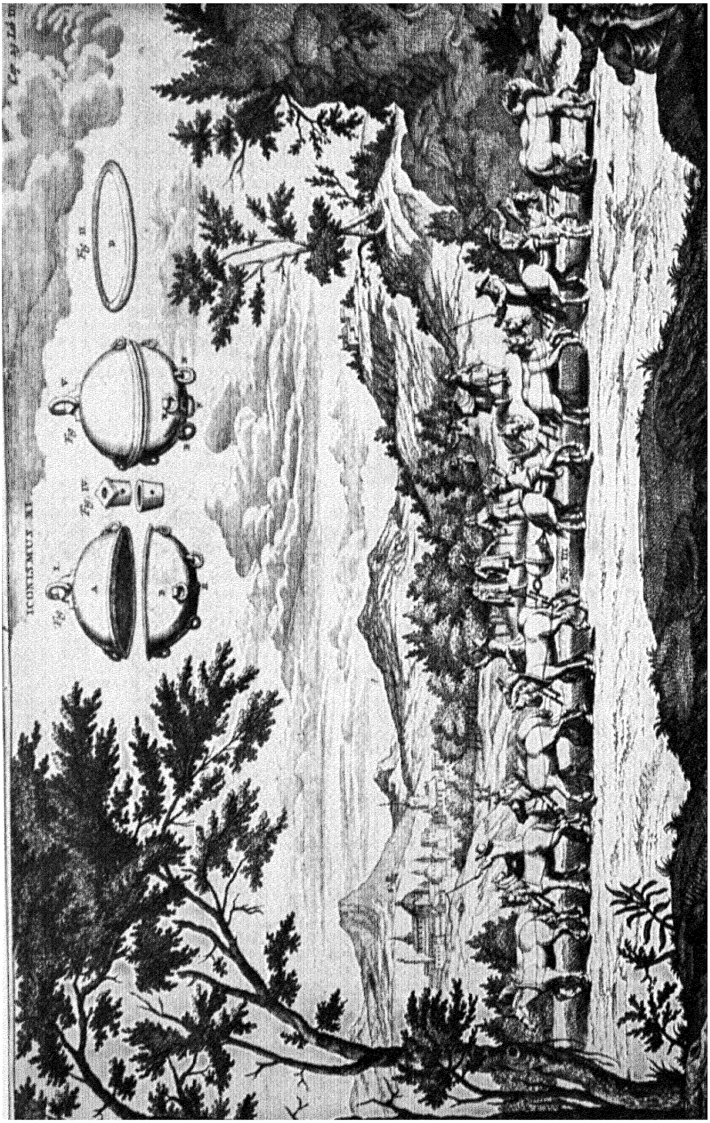


FIG. 26.—Torricelli's experiment

A great many people laughed this explanation to scorn. If the pressure of the atmosphere were the same as that of a column of mercury thirty inches high, that meant that the air was pressing down on us with a weight of fifteen pounds on every square inch. This, they said, was absurd, because such a pressure would crush us. We now know, of course, that the blood and air in our bodies is pressing outwards with an equal pressure. The result is that we are not conscious of the pressure of the atmosphere unless it alters in some way and becomes either less or more than the pressure inside our bodies.

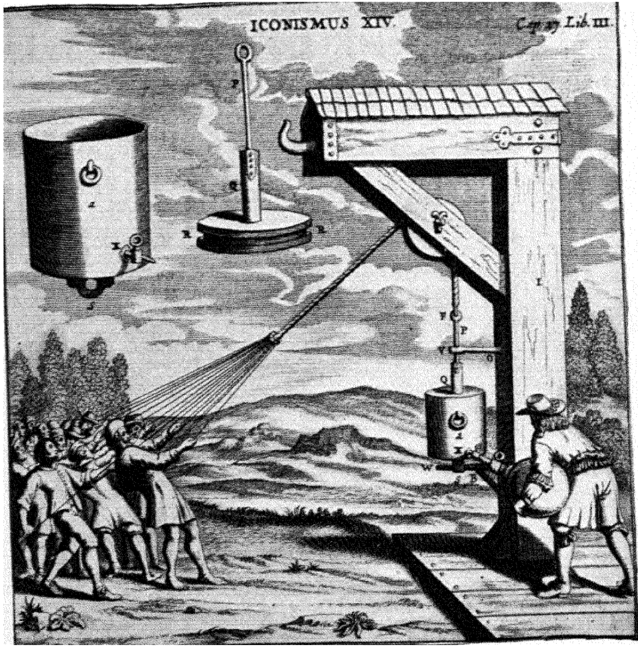
Blaise Pascal (1623–1662).—Torricelli wrote about his experiment to some friends in Paris, and, in this way, a certain very clever Frenchman named Blaise Pascal, who lived at Rouen, came to hear about it. He was very much interested and thought that Torricelli was probably right in his explanation; but before the matter was quite

PLATE XV

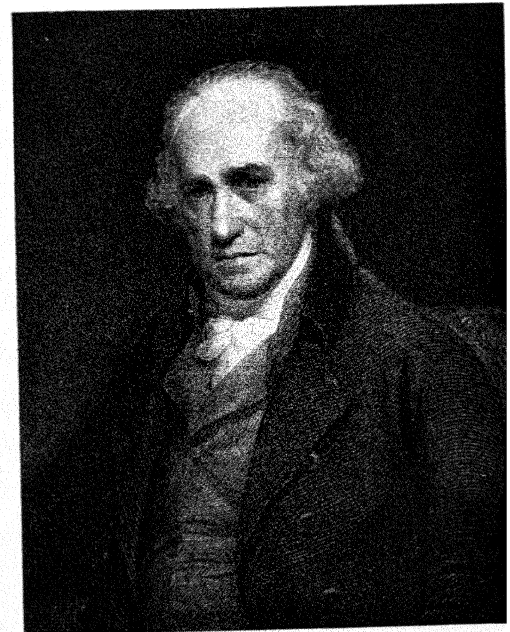


Guericke's First Experiment (the Magdeburg Hemispheres)

PLATE XVI



Guericke's Second Experiment to show the pressure of the Atmosphere



James Watt

settled he felt that it should be tested further. He reasoned that if the column of mercury in the tube were really held up by the pressure of the atmosphere, then, if the latter altered in any way, the height of the mercury column should alter correspondingly. The only way which he could think of to alter the pressure of the atmosphere was to perform the experiment higher up above the earth's surface. Since there was then less air above to press down on the mercury, the pressure would be less. If Torricelli's explanation was correct the column of mercury held up would be shorter.

The only high place near Rouen was the top of the Cathedral tower. So Pascal, when he had got the necessary thick glass tubes, repeated Torricelli's experiment at the foot of the tower and then again at the top. The mercury column was certainly a little shorter, but not enough to satisfy Pascal. He determined that the experiment must be repeated at some place where a greater difference in level could be achieved. The obvious solution was at the foot and at the top of a mountain. Unfortunately there were no mountains near Rouen. Pascal was not at all strong and could not undertake the necessary journey, for travelling in those days was a very arduous matter. However, he had a brother-in-law named Perrier, who lived in the mountainous district of Auvergne. Pascal, therefore, wrote to Perrier describing his experiment and asking if he would undertake to repeat it at the foot and the top of one of the high mountains.

Perrier gladly consented, and prepared two tubes of mercury which he inverted in two separate bowls. One of these he set up at the foot of the mountain and left two men in charge to note any changes which might occur;

and then with a companion he set off with the second tube to the top of the mountain. Sure enough, when they reached the top the mercury column was about three inches shorter than it had been at the bottom. As they came down again they found that the mercury gradually rose in the tube until at the foot of the mountain it was once more the same height as that in the tube which had been left there.

The news of this successful experiment pleased Pascal very much indeed, and it was now quite certain that Torricelli's explanation was the right one. The latter's inverted tubes of mercury, moreover, furnished a very convenient way of measuring the pressure of the atmosphere from day to day, for it was found that this was not quite constant. Such was, in fact, the beginning of the instrument known as the Barometer, which has proved so useful to us in our knowledge of weather conditions. In its more modern form—the aneroid barometer, which does not contain any mercury—it is used in aeroplanes to measure the height above the surface of the earth, for it is known that the pressure of the atmosphere decreases regularly with the height above sea-level.

Otto von Guericke (1602–1686).—At that time news travelled very slowly indeed, so that it happened that on the other side of the Alps from Italy another man was finding out about the tremendous pressure exerted by the atmosphere, in complete ignorance of the experiments of Torricelli and Pascal. This man was Otto von Guericke, a Burgomaster of Magdeburg in Saxony. He had been educated at various centres of learning, and, before his election as Burgomaster, had been chief engineer to the town of Erfurt.

Guericke was drawn to the subject in quite a different

manner from Torricelli. His first interest was in Astronomy. At that time it was still a debated question as to whether the space between the sun and the planets and stars was completely empty or filled with air. Guericke took the former view, for, said he, if the planets move through air, then they will encounter friction and gradually slow down. This, you must remember, was in the days of Kepler, and before the days of Newton, and the movement of the planets was a burning topic. Guericke maintained that the only way to study the motion of the planets was to produce a vacuum and so obtain conditions which were comparable to those of the Heavens.

He had, of course, been brought up in the traditional doctrine that Nature abhors a vacuum. In him, however, was the spirit of Galileo and the new age, and he determined to try for himself and see if he could obtain one. His first attempt consisted in trying to pump the water out of a wooden cask with a suction-pump of the kind we have described, without allowing any air to enter. He found the pump very hard to work, and before long there was a loud hissing as the air from outside forced its way in through the joints. He tried again with two casks, one inside the other; but although he managed to pump all the water out, he found that air had taken its place.

He persevered, however, and next used a copper globe filled with water and attached his pump as before. This time the pumping was so hard that it took two men to work the pump, using all their strength. Then, just as they seemed to be getting on, the globe collapsed with a tremendous report, alarming everybody very much. However, this attempt was obviously more successful than the last, so Guericke had a still stronger globe made

and a better pump and tried again. This time he succeeded and obtained a nearly complete vacuum. The globe was fitted with a stop-cock, or tap, which was turned off when the water had been pumped out. When the stop-cock was opened the air rushed in with such violence that it was very dangerous to stand near. Guericke writes that, even at a considerable distance, one's breath was taken away as the air rushed in.

His next idea was to try to pump out the air from the globe straight away, instead of displacing it by water first. He had to alter his pump a little to do this, but soon succeeded. With this new air-pump he was able to obtain a vacuum fairly easily, and soon devised some very striking experiments to show the enormous pressure exerted by the air on the outside of an evacuated vessel. These aroused great interest and amazement in the people who saw them, and soon the fame of Guericke reached the Emperor's ears. He at once desired to see these things for himself, and accordingly Guericke arranged two very spectacular experiments which he performed before the Emperor Ferdinand III and his Court.

The first experiment has become very famous and is always known as the Magdeburg Hemispheres experiment. A large sphere of about fifteen inches diameter was divided into halves which fitted tightly together with a leather ring in between to make the joint airtight. To a nozzle in one hemisphere the air-pump was fitted, and the air was then pumped from out the globe. It was then shown that, although formerly the halves had separated easily enough, after the globe had been exhausted, they were now held firmly together. Horses were then harnessed to hooks on the globe, eight to either side. Straining with all their might, they were just able to

separate the halves, which fell apart with a loud report (Plate XV).

The second experiment was, perhaps, even more striking. A similar globe, only this time not divided in half, was again evacuated and the nozzle connected to the bottom of a cylinder. This contained a heavy piston fitting the cylinder tightly. Attached to the piston was a rope passing over a pulley and dividing into twenty smaller ropes. Each of these was held by a man standing on the ground. The men had to exert all their strength to keep the heavy piston in position. The tap of the globe was then opened. Immediately the air from underneath the piston rushed into the empty globe, causing such a difference of pressure between each side of the piston that the latter was pushed down violently and with such force that the men holding the ropes were jerked violently off their feet (Plate XVI).

So, in quite another way, Guericke showed that everywhere the atmosphere was exerting this enormous pressure. As a rule it was resisted by an equal and opposite pressure and so was apparently ineffective. If, however, this resistance was removed, a tremendous force was immediately available. It was this force which was to be used in the inventions of the new machines.

II

The Steam-Engine

Dionysius Papin (1647–1712).—It is to a Frenchman named Papin that the origination of the idea of these new engines is usually ascribed, although he himself was never very successful in getting them to work. Inventors generally have to depend upon other workmen for the

making of their models, and bad workmanship may often bring failure when the idea on which the invention is constructed is a perfectly sound one. This was, to a certain extent, the case with Papin's invention; but he was also handicapped by the fact that he had no money of his own and had to depend for the carrying out of his plans on his patron, the Landgrave of Hessen in Germany.

Papin was a French Protestant, and all Protestants were expelled from France in 1685. With many of his fellow-countrymen Papin went to Germany and obtained an appointment at the University of Marburg under the patronage of the Landgrave of Hessen. At this time there was constant warfare with Louis XIV of France, and, although the Landgrave was interested in Papin's invention, he was continually being distracted by other claims on his attention. Consequently Papin was never able to construct a really successful engine, and after a time the Landgrave lost interest. Meanwhile, however, Papin had been in communication with certain members of the English Royal Society. Earlier in his life he had spent some years in England and had known Boyle and his assistant, Hooke, who also had been working on the subject of atmospheric pressure. Hooke had given Papin's plans to a very clever iron-worker, named Newcomen, and the latter had soon constructed a good working engine from these plans. This engine is usually known as Newcomen's engine, but we must remember that the invention really came from the Frenchman, Papin.

Newcomen's Engine (1711).—The engine was originally designed to work a pump to pump the water out of mines and prevent them from flooding.

The piston-rod of the suction-pump was attached to a

weight (W) connected to one end of a lever (L). The other end of the lever was connected to a piston which could move up and down in the cylinder (C). The piston was normally kept at the top of the cylinder by the weight (W). Steam was then passed into the cylinder

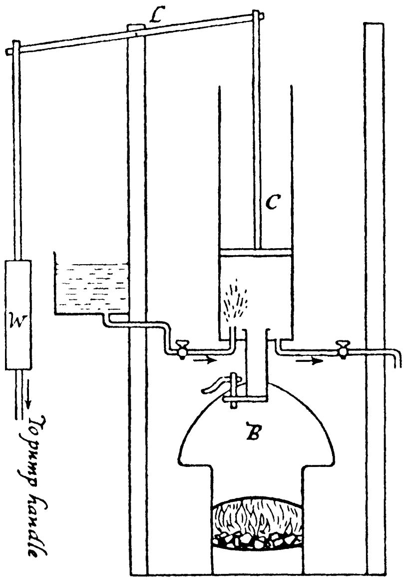


FIG. 27.—Diagram to show the principle of Newcomen's engine

underneath the piston, from the boiler (B), and then the steam was condensed by a dose of cold water from another jet. Now, when steam is condensed to water, the volume becomes sixteen hundred times smaller. The condensation of the steam, therefore, practically caused a vacuum under the piston, so that the latter was immediately pushed down by the pressure of the atmosphere to the bottom of the cylinder. This worked the lever, so causing an upward stroke of the suction-pump. The steam from

the boiler was then turned on again so that steam entered the cylinder and the weight pulled the piston up again. This caused the downstroke of the suction-pump. Thus the only attention the engine needed was the alternate turning on and off of the taps controlling the steam and water jets. There is a story that a lazy boy was put to do this who soon tired of his monotonous job. Being somewhat of an inventor he contrived to tie strings from the taps to the ends of the lever so that the engine itself did the job. Once started, the engine was now self-working. Considerable doubt has been thrown on the truth of this story, but it serves well to show the principle of automatic working.

James Watt (1736–1819).—Newcomen's engines were used in the larger mines for more than fifty years, but they were very expensive, because a tremendous amount of coal was used in producing the steam. The man who made the steam-engine a really practical proposition, and whose name is the most famous in this connection, was James Watt of Glasgow. He was born in Greenock in 1736, and, as a youth, was apprenticed as a mechanic first in Glasgow and then in London. In 1757 he obtained a post at Glasgow University, where his work was to look after the instruments and models used in the science department. Here he met and became friendly with Joseph Black, who was afterwards to become so famous in the scientific world.

It was while Watt was at the university that a model of one of Newcomen's engines came under his hand for repair. He at once saw its disadvantages and set about trying to find a way to overcome them. He realised that the reason why so much coal was used was because a great deal of the steam which entered the cylinder at

once condensed and gave up its heat to the cold cylinder. Only when the cylinder was as hot as the steam did it begin to fill up with the latter. What was wanted was to find a way of condensing the steam when the cylinder was full, without again cooling the cylinder.

It was not long before he saw how this could be done. If, instead of sending into the cylinder a jet of water, a

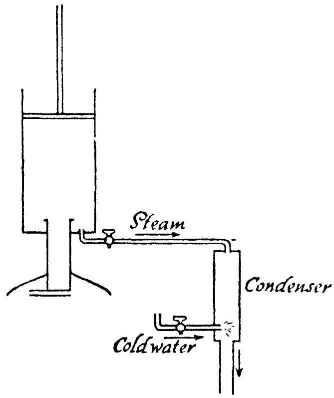


FIG. 28.—Showing how Watt's condenser was fitted to Newcomen's engine

tap was opened connecting the cylinder with a vessel empty of air and kept permanently cold, the steam would rush into this vessel and condense there without cooling the cylinder. This vessel is known as the condenser (see fig. 28).

Watt's difficulty was the same as Papin's, namely, to find the money to get a model made, for he had none himself. At first the owner of the famous Carron Iron Works in Scotland helped him, for he hoped to use the engine in his mines. Unfortunately his workmen made the engine very badly, and it would not work, so Watt had to give it up for the time being. Some years later,

however, he found another man ready to help him. This man was Matthew Boulton, who owned a large factory near Birmingham, where he made all sorts of iron goods. His men made a much better job of the model, which, this time, was entirely successful. The fame of the engine soon spread, and, before long, Watt's engines were being used for all sorts of purposes besides pumping mines.

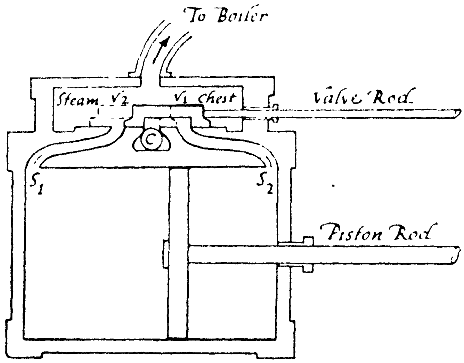


FIG. 29.—Diagram of high pressure steam-engine

When valve is in position V_1 steam enters by S_1 and drives piston to right. This automatically moves valve to position V_2, closing S_1 and opening S_2. The piston is now driven to left and steam on left side is driven to condenser through outlet C. In this way steam enters alternately first one side and then the other, driving the piston backwards and forwards.

These, of course, could now be pumped dry more successfully, and so coal became more plentiful and cheaper. Mills and factories hitherto worked by water-power now changed over to the new steam-engine, and the Industrial Revolution had begun.

As skill in the working of iron increased, boilers were constructed which could stand a much greater pressure of steam. Instead of working the engine by the pressure of the atmosphere, 'high pressure' engines are now used where steam is forced into the cylinder under pressure, first one side of the piston and then the other, and led away

to the condenser—through automatically operating valves. The diagram shows this.

Steam-engines are still greatly used to-day where coal is plentiful, although in many countries with cheap water-power they are almost everywhere replaced by the electric-motor. Their chief use is, of course, in the steam locomotive which draws the majority of our trains.

III

The Internal Combustion Engine

The nineteenth century was the great age of steam-power. In the latter half, however, another kind of engine was invented which to-day bids fair to outrival the older steam-engine. This was the internal combustion engine. In each case the source of the energy which drives the engine is the chemical energy liberated as heat in the combustion of a fuel. In the steam-engine the combustion of the coal or oil (which is used in many ships) takes place outside the engine. In the internal combustion engine the fuel is fired in the cylinder of the engine itself. In this case, of course, the fuel is not coal. Originally it was a mixture of coal-gas and air. Coal-gas is obtained by heating coal very strongly out of contact with air, so that it does not burn. Nowadays a mixture of the vapour of petrol or of a heavier oil and air is most generally used as fuel, although a mixture of gas and air is still employed.

The engine consists of a piston and cylinder, as before. When the piston is near the top of the cylinder the vapour and air mixture is fired by an electric spark generated by the magnet. The hot gases formed expand and push down the piston. The piston is connected to a crank-

shaft which it turns as it descends. To the shaft is fixed a heavy flywheel, which, once started, goes on revolving

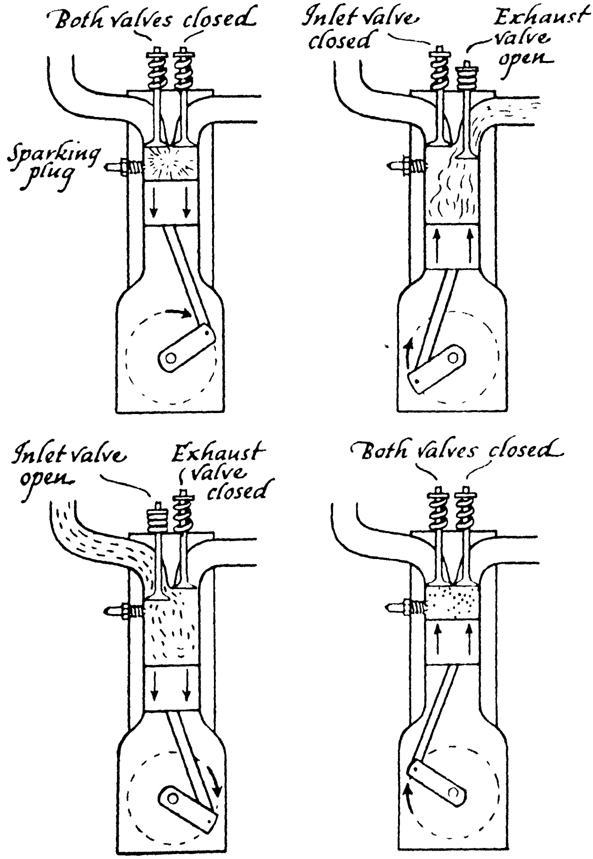


FIG. 30.—Showing the four strokes of a petrol-engine. The valves are worked automatically from the revolving crankshaft

under its own momentum and so pushes up the piston, driving out the burnt gases—the exhaust—through an opening. At this point the crankshaft will probably receive an impulse from the firing of petrol vapour

in another cylinder, and so the piston in the first one is pulled down once more, sucking in above it a fresh supply of petrol vapour. On the upward stroke this is compressed and is fired just as the piston reaches the top of its stroke, starting the whole cycle again. Nowadays there are usually four or six or even more cylinders to an engine, so that the crankshaft gets a succession of impulses during one revolution. In almost all motor-cars each cylinder is fired every fourth stroke of its piston. giving an impulse to the crankshaft. The other three strokes are produced by the revolution of the crankshaft.

(1) The piston is driven downwards by the expansion of the hot gases produced by firing the petrol vapour.

(2) The upstroke drives out these gases through the exhaust.

(3) The following downstroke sucks in fresh petrol vapour.

(4) The upstroke compresses this petrol vapour which is fired by an electric spark just before the next downstroke should begin. The timing of this firing is very important, as every motorist knows.

In motor-cycles a 'two-stroke' engine is sometimes fitted.

The first successful petrol-engine was made by a German, Gottlieb Daimler. He fitted one of his engines to a bicycle, and later used one in a boat on the River Seine. A French firm then began manufacturing carriages carrying a petrol-engine, and so the motor-car originated. In England, an attempt had already been made to do the same thing with the steam-engine, but the 'steam-car' had proved a very cumbersome affair.

At the beginning of the present century motor-cars were improved out of all knowledge, and not long ago it seemed as if motor transport might supersede steam-trains altogether. There is, however, still much to be said for the latter, and, although it is not safe to prophesy anything nowadays, steam-trains will probably remain with us for a while yet, at any rate until electric power in this country becomes cheaper.

In 1900 Count von Zeppelin, a German, built the first great airship with a petrol-motor attached. Hitherto, balloons had been used for travelling in the air, but since they depended on air currents for their movement they were uncertain and risky to use. The airship still depended on its great gas bags for keeping it afloat in the air and overcoming the weight of the cars and engines; but it was now provided with a motor and propeller, and so could be flown in any direction. This first ship cost about £10,000, and only remained in the air twenty minutes. On landing it was utterly wrecked. Count Zeppelin, however, persevered, and by 1906 had another airship built which, this time, was more successful. To-day the German nation owns the famous airship, the Graf Zeppelin, which quite recently has journeyed round the world and contains cabins fitted with every luxury.

It is the aeroplane, however, which has been most successful in the conquest of the air. The petrol engine is used here to draw the machine through the air by means of the propeller which acts as a screw, hence the name air screw. The pressure of the air which results from the high forward speed of the aeroplane acting on the wings, which are so sloped that the front edge is slightly higher than the rear, causes upward pressure on the under surface and a vacuum above the curved upper

surface. Thus sufficient 'lift' is provided to overcome the downward force of gravity.

The pioneers in aeroplane construction were two American brothers, Wilbur and Orville Wright. As early as 1903 they made a machine which flew two hundred and sixty yards; and two years later they made a flight of twenty-four miles at a speed of thirty-eight miles an hour. During the Great War (1914–1918) the use of aeroplanes increased rapidly for military purposes, and since then regular air routes have been set up between all the important world centres. Hardly a month passes now without some new record being made.

It is in land transport that the petrol-engine is especially useful. This is because it takes up comparatively little room and works automatically once started. The electric-motor, which is its rival for stationary power, needs a constant supply of current, and batteries which might supply this are cumbersome to carry. Electrically-driven vehicles, such as trams and trains, are therefore always used along definite routes supplied with lines or overhead wires carrying the current from a generating station.

These three kinds of engines—the steam-engine, the petrol-engine, and the electric-motor—are our main sources of power to-day. Whether they will still hold the field a hundred years hence it is not safe to prophesy.

CHAPTER XIII

Waves of Many Kinds

HEAT, light, sound; these are to form the subject of this chapter. What a dull world it would be without these three! In fact, take them away and the world would almost vanish. Imagine a cold, black, silent, world where the only knowledge of things outside us is obtainable by the sense of touch apart from, possibly, taste and smell; a world where there is no warm sunshine in the summer or cosy fire in the winter; where there are no faces, no colour, no pictures; where there is no speech and no music. Such a world would be so bleak that we cannot be too grateful for our senses which are able to perceive this magic trio.

What is it that we feel when we sit in front of the fire? What is it that enables us to see and so makes the world, to us humans at any rate, such a real thing? What is it that our ears hear and our brain understands as speech and music? These have been troublesome questions throughout the ages, and only comparatively recently have any satisfactory answers been found. Even now our scientists are finding that there is more to come; we know only a part.

I

Heat

When, in 1789, Lavoisier drew up a list of those substances which he considered to be elements, he headed his list with 'heat' and 'light.' In so doing he was in line

with the general opinion of the times which considered that both heat and light were invisible and weightless fluids, but nevertheless of definite substance. Very much the same conception was also held of magnetism and electricity. Lavoisier gave the name of 'caloric' to that substance which caused the sensation of heat when it entered the body.

It is quite clear when we read their books that neither Boyle nor Newton shared this view of the nature of heat. Both of them evidently considered that the cause of the sensation of heat, or of any of the common effects associated with it, was always motion of some sort. However, neither laid much stress on this, and so did not change the prevailing ideas.

Let us now consider some of the most important facts about heat and its effects:

1. *Heat and Chemical Action.*—The addition of heat to chemical substances always makes them react together more easily. Very often, when two substances react together to form one or more new substances, quite a large amount of heat is also formed. Heat is, therefore, intimately connected with chemical reaction.

2. *Expansion due to Heat.*—When imparted to any solid, liquid, or gas, heat nearly always causes expansion, provided it does not bring about a chemical change.

The old explanation of this was that the fluid heat, or caloric as Lavoisier called it, pushed its way in between the particles of which the body was composed, moving them farther apart and so making the body, as a whole, take up more room. Galileo used this effect in making the first thermometer. This consisted of a glass bulb, with a long glass stem dipping into water which had previously been made to rise part of the way up the stem.

When the air in the bulb became hotter the air expanded and pressed the water down the stem. When it cooled, it contracted and the water rose. Later the expansion of a liquid, instead of a gas, was used to show a rise in temperature. We cannot here follow all the improvements which were later made in the thermometer. You will easily see a great many of them for yourself if you look at a good modern thermometer.

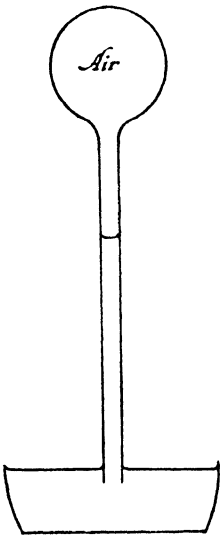


FIG. 31.—A simple air thermometer

3. *Latent Heat.*—At first little distinction was made between the 'temperature' of a body and the caloric which caused it. It was generally assumed that the addition of caloric to a body always produced a rise in temperature. That this was not the case, however, was first pointed out by Dr Joseph Black in 1756, just after he had completed his important chemical work on the nature of chalk, quick-lime, and the alkalis.

Two things attracted his attention: the length of time it takes ice to melt, or boiling water to turn completely to steam; and the fact that while either of these changes is taking place there is no rise in temperature, although heat, or caloric, is continually being added.

On our modern temperature scale, when ice is melting, the temperature remains at 0° C. as long as any ice remains. When water boils at normal pressure the temperature does not rise above 100° C.

He explained this extraordinary disappearance of caloric by supposing that the latter combined with the ice or

boiling water in a kind of chemical combination to form the new substances, either cold water or steam. It did this in perfectly definite amounts. Only when the right amount of caloric had been added for the weight of ice, or boiling water, was there any further rise in temperature.[1] The caloric which apparently disappeared because of its combination with the ice, Black called 'Latent' or hidden heat.

Black then set about devising a way to measure this latent heat. His method is the one we still use to-day. He decided that the best way to measure a quantity of heat was to find its effect on the temperature of a given weight of water. He showed that a pound of ice was just melted by the heat given out by a pound of water when it cooled from 172° F. to 32° F.—that is, to its freezing-point. In other words, a pound of ice at 32° F. (or 0° C.) mixed with a pound of water at 172° F. (or 77·8° C.) will result in two pounds of water at 32° F. (or 0° C.). There were thus two possible units in which caloric could be measured. The unit might either be:

(1) the amount of heat required to change one unit weight of ice into a unit weight of water without changing the temperature, or

(2) the amount of heat required to raise the temperature of a unit mass of water 1°.

The latter was eventually chosen by scientists as the unit they preferred to use. To-day the international scientific unit of heat is the *calorie* which is the amount of heat

[1] It is important to remember that neither the temperature of melting ice nor that of boiling water can ever be raised by the further addition of heat. The rise in temperature which finally occurs will be in the water formed from ice, in the one case, and in the steam from the boiling water in the other. The latter is often called 'superheated' steam, and it is above the temperature of boiling water.

required to raise the temperature of one gram of water from 15° C. to 16° C. The unit in everyday use in England is the British Thermal Unit, or the amount of heat required to raise the temperature of one pound of water through 1° F. The Therm is equal to 100,000 B.T.U.

4. *Heat Capacity*.—It was already known that different substances required different quantities of heat to raise their temperature by the same amount. Another way of putting this is to say that it was known that some substances took longer to get hot and cooled more slowly than others. We all know that water 'holds the heat.' Black's work showed how a measurement could be made of these differences. In this way the idea of heat capacity was introduced. To-day we define the heat capacity of a substance as the amount of heat required to raise its temperature through 1° C. The science of measuring heat is known as calorimetry. Heat may be weightless, but it is certainly measurable. Like matter which has weight, it never disappears so that no trace of it can be found. As the scientists say, 'it is always conserved.' Because of this, no doubt, Lavoisier felt justified in including it in his list of elements.

Count Rumford (1753–1814).—The next man to add to our knowledge concerning heat was that Count Rumford by whose efforts the Royal Institution was founded, where Davy and Faraday found such opportunity of distinguishing themselves. Count Rumford was by birth an American, Benjamin Thompson, and spent his youth in New England not many miles from that other American, Benjamin Franklin, the discoverer of the nature of lightning. As a young man he took part in the American

War of Independence on the American side; but for some reason his loyalty was suspected and he fled to England. After some years his love of a military life took him to Austria to join in a war in which she was involved, and later he took service with the Elector of Bavaria who gave him his title of Count Rumford. On the death of the Elector he went to live in Paris, where he was treated with honour by Napoleon, who was invariably hospitable to men of Science.

Heat Produced by Friction.—It was while in Bavaria that his work in connection with the nature of heat was carried out. Although in the majority of its reactions the nature of heat is satisfactorily explained as a weightless fluid, there was one case which was difficult to explain in this way. This was the production of heat by friction. Here heat was produced apparently from nowhere, for no change could be detected in the bodies between which the friction occurred. The common explanation during the eighteenth century was that the friction rubbed or squeezed out the fluid heat from between the particles of the bodies. That this explanation did not please either Boyle or Newton we have seen.

Count Rumford was struck afresh by the problem when boring cannon in a munition workshop in Munich. He found that the metal became extremely hot. He carefully examined the metal of the cannon, the borers, and afterwards the brass shavings. He found no change, however, in the brass of the shavings when he compared them with the original mass from which they came. He then carried out a further boring, but with two alterations in the conditions. He used very blunt tools, and arranged that the metal should be surrounded with water so that all the heat produced would go into the water.

The result was that the water got hotter and hotter. After two and a half hours' boring, to the great amazement of all the spectators, it actually boiled and remained boiling as long as the boring was continued. This was the first time, at any rate on record, that water had been made to boil without the use of fire. Moreover, the supply of heat was, apparently, inexhaustible, a veritable widow's cruse.

Heat a Form of Motion.—Now Rumford recognised that although no heat came from outside, something else had to be supplied all the time. *This was motion.* The boring was carried on by the continual movement of two horses walking in a circle. Rumford, therefore, came to the conclusion that heat could not be a material substance. It must be a form of motion. Unfortunately his conclusion was not accepted by the scientists generally, their minds being occupied with other, as they considered, more weighty affairs at the time.

Sir Humphry Davy.—Young Humphry Davy, as he still was then, was interested, however, and was led to try an experiment of his own. In this experiment he used clockwork to produce heat by friction. The machine was placed on ice in a globe evacuated by an air-pump, and used to melt some wax. In the ice was a cavity containing water, which remained unfrozen during the experiment. According to the old theory, the heat or caloric which melted the wax must have come from the bodies in contact with the clockwork—that is, from the ice. But if the ice had lost heat, then the water in it would have frozen, which did not happen. Davy, therefore, concluded that the heat must have been produced by the motion of the clockwork.

In this way Davy was converted to Rumford's views.

He concluded that the friction caused the molecules of the wax to vibrate and that this vibration was heat. To-day, this is the view held by all scientists, but it was not generally accepted until some forty years after the time of Rumford's and Davy's first experiments.

Julius Robert Mayer (1814–1878).—In the year 1840 there lived in a little German town named Heilbronn, not very far from the famous university town of Heidelberg, a young doctor named Julius Robert Mayer. He also was very much interested in this curious appearance of heat in cases where no corresponding loss of heat could be found. He recognised that the heat which appeared during friction was not the only example of such an unaccountable appearance. Parallel cases were to be found in the heat which was continually generated in our bodies, and in the heat generated by the electric current so that a wire carrying a current could be made to glow. After long and careful thought on the subject he adopted Rumford's and Davy's view on the source of heat produced in friction. What is more, he extended it so that it would cover the two cases we mentioned as well as others which, on further thought, he realised were similar examples of the same phenomenon.

Meaning of Work.—In the last chapter we talked at some length about the meaning of force. A force may act on a body but will only move it if it is great enough to overcome the resisting force. Unless the force moves the body it does not do any work. If it does move the body we measure the amount of work it does by multiplying together the amount of force and the distance through which it moves the body.

Work done = Force × distance (measured in the direction of the force).

Thus, when the cannon was bored, the work done was measured by the force used in turning the borer multiplied by the distance through which the horses moved.

When work is done we say that energy is used up. During friction, therefore, energy disappears, but heat appears.

Forms of Energy.—Various kinds of force were known to Mayer. In addition to the force of gravity, there were electrical force, magnetic force, the force which could be exerted by a moving body, and chemical force. Mayer said that all these different kinds of force were merely different forms of one and the same thing, which we now call Energy. To the list he also added heat. Whenever one of these kinds of energy disappears, said Mayer, one of the others always appears in its place:

(1) When heat appears during friction it is because energy of motion has disappeared.

(2) When heat appears in a wire carrying a current it is because electrical energy propelling the current has disappeared.

(3) The electrical energy propelling the current only appeared when chemical force disappeared in the cell, *i.e.* when the zinc dissolved in the sulphuric acid.

(4) If the electric current was produced by a dynamo, then the energy of motion was turned into electrical energy.

Now, whenever work is done on a body, the energy used up in doing the work is always stored in the body and can generally be made to appear again in one or other of its forms. Generally, in a machine, not quite so much work can be got out of it as is originally put in, and up till the time of Mayer there seemed a complete

loss of a certain amount of work. Mayer, however, showed that this was not the case. Always there was developed, whilst the machine was working, a certain amount of heat because of the inevitable friction between its parts. This heat, according to Mayer, was the exact equivalent in energy of the work which had apparently been lost. From experiments on the compression of a number of different gases which had been carried out by other people, and also from an experiment in a factory which he arranged himself, Mayer found that in all cases the heat formed and the work lost were proportional to each other.

James Prescott Joule (1818–1889).—Soon after Mayer began to work on this subject in Germany, a young Englishman named James Prescott Joule became interested in the same thing, though quite independently. He first investigated the heat generated by an electric current. He was able to find out just how much heat was generated in a wire if the strength of current flowing and the resistance of the wire were known.

Mechanical Equivalent of Heat.—Next he generated a current in a wire by means of a small dynamo in such a way that he could measure the work which was done in turning the coil of the dynamo. In this way he found how much work had to be done to develop one calorie of heat in the wire. This quantity is known as the Mechanical Equivalent of Heat and is a very important one.

Joule's early experiments were not very accurate, but he went on to devise a great many others in which the heat, developed in all sorts of ways, was measured and its mechanical equivalent calculated. These experiments have become very famous. Indeed, Joule won much

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more honour and fame for his work than Mayer. It is one of the blots on the pages of the history of science that the value of Mayer's work was never properly appreciated at the time it was published. Worse still, when later he tried to get his work recognised, he was told that it was not original and that he was only copying somebody else. It will be agreed that this was a horrible accusation and was a terrible blow to Mayer. Misfortune also befell him owing to ill-health and bad treatment by his fellow-doctors, so that the remainder of his life was very unhappy. We may be proud, perhaps, that it was one of our countrymen, John Tyndall, Faraday's successor at the Royal Institution, who put up a great fight for Mayer and gained him his deserved recognition during the last few years of his life.

This great principle which the work of Mayer and Joule established is always known as the *Principle of the Conservation of Energy*. It states that the sum-total of all the energy in the world is constant. If energy in one form disappears, an equivalent amount of another form appears somewhere else.

II

Sound

Having established the fact that heat is a form of energy, and not a material substance, let us now turn to sound. The Greeks seem to have known that sound was always caused by vibration and that the air was necessary for its transmission. In the second chapter in Part I we heard how Pythagoras, listening to the notes coming from the striking of iron on the anvil, was led to certain experiments with stretched strings, as a result

of which he found the connection between the length of the string and the note sounded.

Leonardo da Vinci went further. He suggested that sound was carried by waves through the air which were comparable with waves in water. He explained an echo as the sending back or reflecting of a wave of sound from a hard surface, such as the wall of a building or a mountain-side. By timing the interval between the sending of a sound and the hearing of the echo, he calculated the rate, or velocity, with which sound travelled.

Probably Leonardo understood very well the characteristics of wave motion, but it is Newton who is famous for his investigations on this subject. His explanation is difficult, as he invariably talked in mathematical language. It is very necessary, however, to have a clear idea of what is meant by this expression, wave motion, in order to understand the battle which waged over the question of the nature of light.

It is always simplest to begin with that with which we are most familiar, so we will make a start with water waves. If a stone is dropped into a pond, the water all round the stone becomes heaped up, but as the stone sinks it returns to its original level. Because of its 'inertia' —that is, because of its tendency to go on moving until something stops it—the surface water slightly overshoots the mark and sinks below this original level. The water underneath will only be compressed to a small extent, however, and quickly succeeds in pushing it back again. Again, because of its inertia, it overshoots the mark and heaps up; and the whole process starts again. In this way the water on the surface, at the point where the stone sank, oscillates up and down, the oscillations only gradually dying down. It cannot oscillate, however, without

disturbing the water round it. A circle of water immediately around our oscillating point begins to oscillate too, forced along by the moving water next to it. It starts, however, just a little later, so that, when the surface water of the original patch reaches its lowest point, the next circle has not got quite so far.

In the diagram, XY represents the surface of the water before the stone was dropped in. Now, let us consider the surface of the water a few seconds after the stone fell. The disturbed patch of water, O, has already made a number of oscillations. In the diagram the

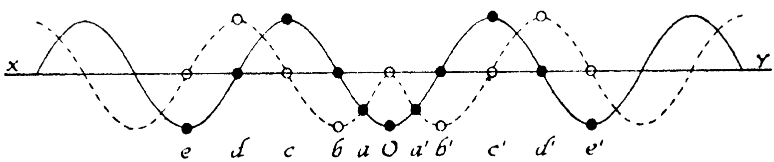


FIG. 32.—To illustrate the principle of water waves. The two positions are shown by (1) the continuous and (2) the dotted wavy lines

portion O has reached the lowest point and is just going to start moving up again. The portions *a*, *a'* on either side have not quite reached this level and are still moving downwards; *b*, *b'* are passing the original level in a *downward* direction; *c*, *c'* have just reached the highest point before moving down again; *d*, *d'* are passing their original position but in an *upward* direction; while *e* and *e'* are portions oscillating exactly in time with the original portion O. The surface of the water then, in the direction XY, has exactly the appearance of the continuous wavy line joining the particles. Now, if we look at the next diagram, we get an idea of what the whole surface looks like. The dotted rings join all points which are in positions corresponding to *c* and *c'* in the first diagram. Together they form the 'crest' of the waves. The black

rings join all points in positions corresponding to *e*, *e′* which form the troughs.

Now turn back to the figure 32 and let us consider the surface a moment later, as shown by the dotted line. O has now reached the original level moving in an upward direction. The portions *d* and *d′* now form crests which

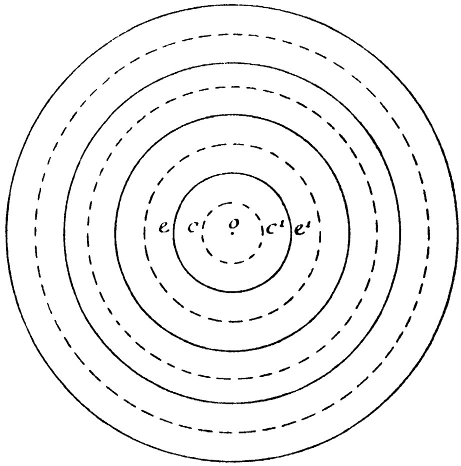


FIG. 33.—The dotted lines represent crests, and the black lines troughs

have moved outwards away from O. The spread of ripples outwards from the point where a stone sinks is a familiar sight to all. It is most important to realise that the actual water does not move *outwards* at all, but only *up and down* along the same vertical line. It is only the wave or shape of the surface which moves outwards.

When a tuning-fork is sounded, waves of sound spread out in all directions through the air. The vibrations of the tuning-fork make the particles of air round it vibrate; these affect the next layer and so on. The vibration thus spreads outwards till finally the layer of air in contact

with the drum of our ear is set vibrating. The drum of the ear is made so that it also can take up the vibration and transmit it to the brain, when a 'sound' is heard.

There is one important difference between sound waves and water waves. The particles of water, as we have seen, vibrate in a direction at right angles to the way in which the waves are travelling. The particles of air, however, vibrate in the same direction. What really happens is that, as the prongs of the tuning-fork move outwards, they compress the air all around. This compression is passed on to the next layer, and the next, and so on. We say that a pulse, or wave of compression, is sent out. As the prongs of the fork move back, however, the air can expand again and so a pulse of 'rarefaction' quickly follows the one of compression. Galileo showed that the more quickly these pulses followed each other the higher was the note sounded.

Except for the direction in which the particles vibrate, there is no essential difference between the wave motion in air which causes sound and wave motion in water. As we have seen, Newton studied the question of wave motion very carefully. One of the most important results of this study was that he showed that the rate at which sound travels through the air depends upon the temperature of the air, the barometric pressure, and the amount of water vapour in it. He also showed how to calculate this velocity for a given set of conditions.

Although sound, as a rule, travels through air to reach our ears, it will pass through other forms of matter as well. It generally does so at a faster speed. There are many stories of Red Indians who, by holding their ears close to the ground, hear sounds of horses a great way off. The sound travels quickly through the earth,

and does not get deflected or absorbed by obstacles. In travelling through the air it meets solid obstacles which either absorb it or else reflect it off in another direction.

III

Light

The nature of sound, then, was fairly well understood at the time of Newton. The same could not be said about the nature of light. Let us quickly summarise what was known as to the *properties* of light.

(1) It appeared to travel in straight lines—that is, it cast sharp shadows and did not bend round corners.

(2) It would pass through some kinds of matter—transparent bodies, but was absorbed by others—opaque bodies; while a third kind reflected it back.

(3) When light was reflected from a surface, the angle at which the ray struck the 'mirror' was the same as that at which it was reflected.

(4) When light passed from one transparent medium to another it was bent or refracted. It took a long time to find the rule showing just how much the ray was bent; but just about twenty years before Newton was born a Dutch professor named Willebrord Snell had discovered this rule.

(5) A Danish contemporary of Newton's, Olaus Roemer, showed from his astronomical observations that, although light travelled very quickly, far more quickly than sound, it did take a definite time to travel. For a long time it had been thought that it travelled instantaneously.

(6) We have already seen how Newton himself showed that white light can be split up into colours by passing it through a prism.

All this tells us quite a lot about what light *does* but very little about what it *is*..

The popular theory at that time was that light consisted of streams of very fast moving tiny particles travelling in straight lines. These particles would rebound from certain surfaces just as a ball rebounds when it strikes a wall obliquely. They would change their speed when going from one medium to another, and this would cause them to change their direction, or become refracted.

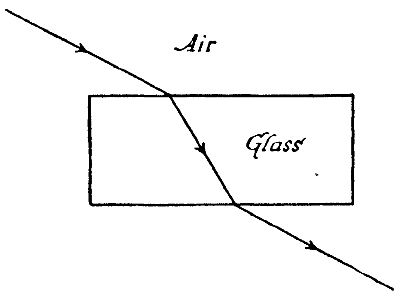


FIG. 34.—Showing the refraction of light in glass

Christian Huyghens (1629–1695).—During the first half of Newton's life there was living in Holland an older man who advanced an alternative theory as to the way in which light travels. This man's name was Christian Huyghens (pronounced Hoygens). There is not much to tell about his life; he had plenty of money and could devote himself to the study of mathematics and science.

Now Huyghens saw one objection to what was known as the 'Emission' or Corpuscular Theory of Light (that is, that the source of light emitted streams of corpuscles). If two streams of particles crossed one another's paths, the particles would collide and fall to the ground. For instance, it would be difficult to see how two people could look straight at each other without the rays of light by

which they saw each other, colliding and stopping half-way.

Huyghens, therefore, suggested that light, instead of consisting of moving particles, was similar to sound and travelled in waves. These could cross each other and still go on undisturbed. There was this difference, however. While sound could not pass through a vacuum it was known that light could. Now waves must travel through something; there must be particles to vibrate and so transmit the waves. Huyghens, therefore, saw that, according to his theory, when every kind of matter, even air, has been removed, space still contains something which can vibrate. This something he called '*Ether.*'

Huyghens was able to show, by mathematics, that if light really consisted of a train of waves it should show all its observed properties except that it should bend slightly round corners of objects in its path, instead of casting sharp shadows as it appears to do. This last seemed a very important objection to Newton. He examined shadows very carefully and could see no blurred edge in those cast from a point source. If the light really spread out round the corners, the edge of the shadow should be slightly blurred.

Newton, therefore, made up his mind that this objection was more important than the one Huyghens raised against the Emission Theory. He argued that if the particles in the latter were very small, the chance of their colliding would not be nearly so great. Newton, himself, probably never definitely made up his mind in favour of either theory. Certain of his writings were, however, misinterpreted as deciding definitely for the Emission Theory.

Newton's genius was so greatly respected that this

reputed decision was accepted both by his contemporaries and his successors. During the whole of the eighteenth century the universal conception of a ray of light was of a stream of tiny particles or corpuscles moving in straight lines with extremely high velocity. Huyghen's Wave Theory lay forgotten and discredited until it once more found an adherent in Thomas Young at the beginning of the nineteenth century.

Thomas Young (1773–1829).—Thomas Young was born in Somerset in 1773, and appears to have been an infant prodigy. He could read at the age of two, and at six was reading books which most people left till a much riper age, if, indeed, they read them at all! He qualified as a doctor, but, being comfortably off, he did not practise to any great extent.

During his medical training he became very much interested in the anatomy of the eye and the power of vision. From that it was a short step to the nature of light itself. For two years, from 1802 to 1804, he also was a lecturer at the Royal Institution. It was during this period that he gave to the public the conclusions he had come to on this subject. Unfortunately, Lord Brougham, who afterwards became Lord Chancellor of England, also dabbled in science. He took it upon himself to ridicule the views of Young in some articles which appeared in a very celebrated magazine, the *Edinburgh Review*. As is so often the case, the power of ridicule and satire is strong, and Young's views received no further notice from the scientific world for the time being.

In studying the question of the nature of light, Young read the books of both Newton and Huyghens. In pondering over the merits of the rival theories he saw that certain things could be predicted from the wave theory

which could not take place if the Emission or Corpuscular theory were the true one. He arrived at this conclusion by considering what would happen if two sets of similar waves, moving with the same velocity, crossed the surface of a still lake and met in a narrow channel leading from the lake. The effect produced on the water in the channel would obviously be the joint effect of the two sets of waves. If they met in such a way that the crests of one set coin-

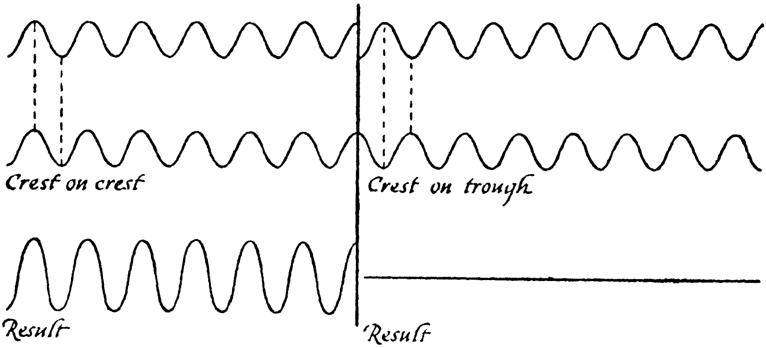


FIG. 35.—Showing the combined effects of two trains of waves

cided with the crests of the other, then crests of twice the size would be formed. If, on the other hand, the crests of one set coincided with the troughs of the other, then these would neutralise each other and the water would remain smooth.

Young's next step was to see whether he could produce such an effect with light. Could he, in any circumstances, 'add light to light and get darkness?' If he could, then, in his view, the issue between the two theories would be settled in favour of that of Huyghens. This is how he set about it.

He produced two small sources of light by pricking pinholes close together in a visiting-card and letting light

from a single source pass through the holes. In this way the effect, on the other side of the card, would be as if the light were coming from two sources. In the diagram (S) is the original source of light; (A) and (B) are the two pin-holes. (C), (E), (D), and (F) is a screen on which the light is received. Now, if light consists of corpuscles, then the whole of the patch C, F should be illuminated, but E D should be twice as bright as C E and D F, since it receives light from both A and B. Suppose, on the other hand, Huyghens was right. From A and B two

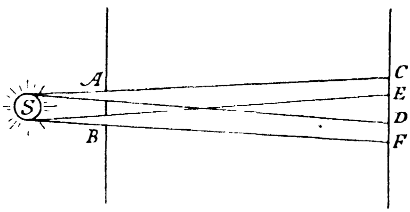


FIG. 36.—Illustrating Young's experiment

trains of waves would meet between E and D. The resulting light would be the combined effect of both sets of waves. Where a crest of one wave coincided with a crest of the other the light would certainly be twice as bright. But at other points crest would meet trough, and the result would be darkness. In this case one would expect both light and dark patches on E D.

Young viewed a small and rather distant source of light through the pinholes, so that his eye corresponded with the screen C E D F. The light then appeared as a patch, bright round the edges, but with the centre crossed by dark bands. The experiment had decided in favour of Huyghens and the Wave Theory of Light.

As we have seen, although Young himself was convinced, he did not succeed in convincing anyone else.

Augustin Fresnel (1788–1827).—Luckily, a dozen years later, a younger Frenchman named Fresnel, working independently along the same lines, demonstrated by a still better experiment the 'interference' of light, as the production of dark bands in the manner described is called. His results were received with proper respect by his countrymen. As he was able to back up his experimental result with a mathematical argument, dear to the heart of every scientist of that day, the Wave Theory of Light was almost immediately universally accepted. Until his work was published, Fresnel had not known of Young's earlier proof ; but immediately he heard of it he wrote to the latter at once acknowledging his priority.

Fresnel is usually acknowledged to be the founder of the Wave Theory of Light, as he undoubtedly produced the fullest and most convincing proof of its truth. It is impossible to follow the proof here. In addition, he showed that Huyghens' original suggestion that the wave motion of light is similar to that of sound (except that it travels in a different medium) must be altered in one particular.

It had been known for some time that a ray of light behaved in rather a peculiar way when it passed through certain kinds of crystals. It split into two rays. Fresnel showed that this peculiarity could be fully explained if light waves were compared with water waves rather than with sound waves. That is to say, the vibrations of the ether must be imagined as taking place at right angles to the direction in which light is travelling, and not in the same direction. Proof of this also is too complicated to go into here, but the result is very important to remember. We usually describe the vibrations of light as 'transverse' and those of sound as 'longitudinal.'

It ought perhaps to be mentioned here that, after all, the Wave Theory has not been able to explain everything. New facts discovered by modern physicists have led to the adoption of a theory which is a combination of both the Emission and the Wave Theories.

IV

The Spectrum

We must now see how this new wave theory explains the colours which are obtained when white light passes through a prism. Newton had supposed that the particles of the seven colours of light were of different sizes, those of the violet being the smallest and of the red the largest. According to the new theory the waves of the violet light were the shortest and the waves of the red light the longest. The length of the wave is measured from one crest to the next one. All light waves are very short indeed; about 5000 go to 1 centimetre.

Radiant Heat.—In 1800, just before Young had published his ideas on the nature of light, Sir William Herschel, an astronomer of whom we shall hear more later, placed the bulb of a very sensitive thermometer in various parts of the spectrum obtained by passing sunlight through a prism. He found that in all parts of the spectrum there was heat falling on the screen, the rise in temperature increasing as the thermometer was moved from the violet to the red end. He then tried putting the thermometer just outside the spectrum. At the violet end there was no rise in temperature, but the thermometer was affected over a distance of 1½ inches beyond the red end. This meant that as well as light rays coming through the prism there were also invisible heat rays, some

of which were bent less than the red rays of light. When the wave theory was established it was realised that these heat waves were really just the same as the light waves, except that their wave-length was a little longer. It is the peculiarity of our bodies which makes us 'see' certain wave-lengths as light, but only feel others as heat. There is nothing essentially different in the waves themselves.

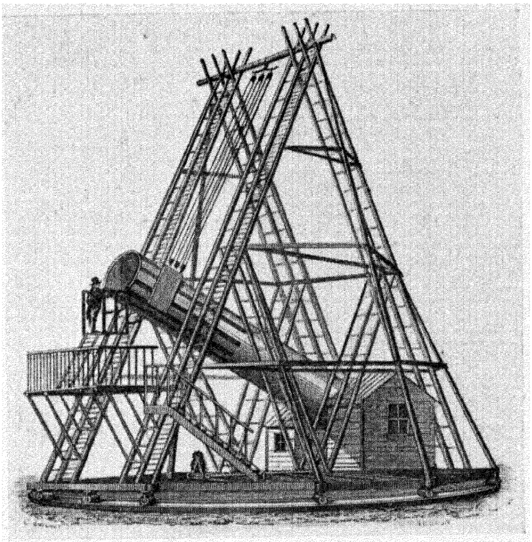
Heat is always a form of energy, but it does not always consist of waves in the ether. When anything is hot the molecules of which it is composed are moving more rapidly than they were when it was in a cooler state. The molecules are never absolutely still. If they were, the body would possess no heat; its temperature would be at absolute zero, which is 273° C. below the freezing-point of water. Such a low temperature has never been reached. The movement of the molecules in a solid is a kind of vibration, the molecules keeping their same relative position. In liquids the movement is more at random; and in gases the molecules move very rapidly in all directions.

The violent motion of the molecules of a very hot body, such as the sun, disturbs the surrounding ether, and waves of 'radiant heat' are sent out in all directions. When these waves meet some other body they give up their energy to its molecules which, therefore, move faster than they were doing, and so the temperature of this body rises. Gases, as a rule, are not able to absorb radiant heat. That is why the heat from the sun passes through the envelope of air without heating it and is not absorbed until it reaches the earth. A cloud, however, is able to absorb a certain amount, and so shuts off the heat of the sun from the earth. Radiant heat obeys just the same laws of reflection and refraction as light rays.

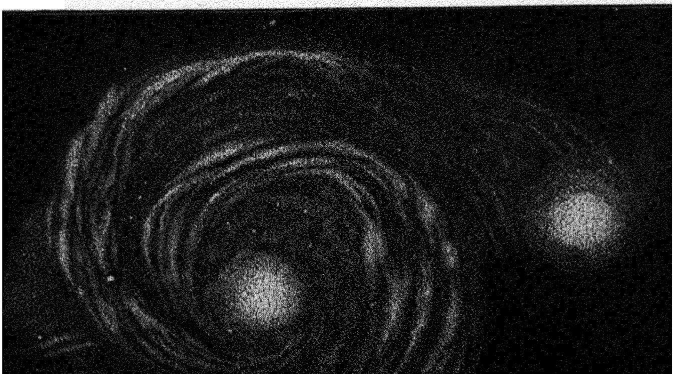
Ultra-violet Rays.—If you know anything about photography you will probably know that certain chemical substances, such as silver chloride and silver bromide, are darkened on exposure to light, and that this fact is made use of in taking photographs. The year after that in which Sir William Herschel found that the spectrum extended beyond the red end, it was found that there was also an invisible portion beyond the violet end, which, although it could not be seen, would still darken silver chloride paper. These new rays became known as the ultra-violet rays and the radiant heat rays were generally called the infra-red rays. Thomas Young measured the wave-length of these new ultra-violet rays, and found, as might be expected, that their wave-length was shorter than that of the violet light. It has since been found out that it is the ultra-violet light from the sun which possesses the health-giving properties. Ordinary glass absorbs these ultra-violet rays, but a certain kind of glass called 'vita-glass' lets them through, so that it is a very good thing, if one can afford it, to have windows fitted with this glass.

X-rays.—The existence of ultra-violet rays was discovered in 1801. In 1895, nearly a hundred years later, it was discovered that the spectrum extended even beyond these. In that year Professor Röntgen of Würzburg discovered the rays which were first known as Röntgen rays but now are more usually called X-rays. These rays consist of very rapid vibrations in the ether, travelling in very short waves. They are very penetrating and will pass through most solid material with the greatest of ease. Only several inches of lead can be depended upon to stop their passage entirely. A few years after Röntgen discovered his rays it was found that the same kind of rays

PLATE XVIII



Herschel's Giant Telescope



A Spiral Nebula

were being given off continually from all radio-active substances. The best known of these, of course, is radium. As you know, radium is now used by doctors in their efforts to cure certain diseases, such as cancer. Great care has to be exercised in its use, because the radiation which it emits is very powerful and causes bad burns if it touches the flesh. Accordingly, it is always kept in lead tubes, and, when not in use, is surrounded by blocks of lead and kept carefully locked in a safe under one person's charge.

The rays given off from radium are of even shorter wave-length than Röntgen rays, and possess greater penetrating power. Röntgen rays are used for taking X-ray photographs. A stream of rays is sent through the limb, say, which is to be photographed, and allowed to fall on a photographic plate. The denser parts, such as the bone, stop the rays to a greater extent than the flesh and muscle, and this difference shows up on the plate, so giving a picture of the inside of the limb. Many shoe shops keep an X-ray instrument, where you can see this for yourself.

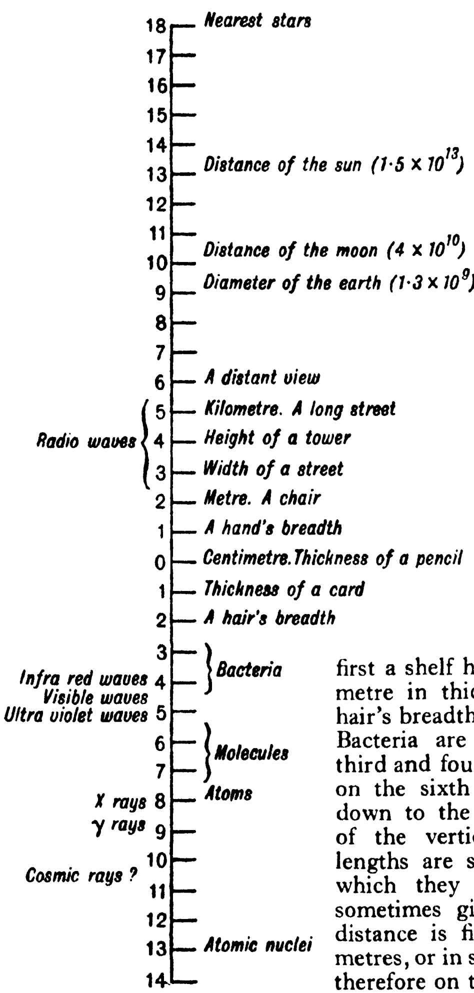
Wireless Waves.—Finally we come to the 'wireless' waves or radio in such constant use to-day. Maxwell had predicted that such waves could be produced, and a German professor, Heinrich Hertz, actually obtained them in 1887. In 1901 an Italian named Marconi showed that they could be put to practical use by sending messages in the morse code from England to Newfoundland. During the twentieth century innumerable scientists and engineers have been at work on the subject, with the result you know very well. Day and night, all over the world, waves are being sent out from innumerable broadcasting stations, and picked up by the receiving sets in

countless homes. Here, by means of the head-phone, or loud-speaker, they are turned back into sound waves exactly similar to those which originally produced them.

Now these wireless waves are similar in nearly every respect to light waves. They are caused by vibration set up in the ether, and they travel with exactly the same speed as light. The essential difference between light waves and 'wireless' waves is that, while the distance between two 'crests' in a train of light waves is only a fraction of a millimetre, that between two crests in a train of wireless waves is some hundreds of metres. The wave-length of the waves sent out from Droitwich. giving our National Programme, is 1500 metres, while the London Regional programme is sent out on a wave-length of 342 metres. Lately, much shorter wave-lengths have been used by some stations, but they are all very big indeed compared with those of light.

All the other kinds of waves, of which we have spoken, affect some part of our bodies, but, at any rate, to our knowledge, wireless waves have no effect whatsoever upon us. They can, however, be made to affect an electrical instrument—that is, a wireless receiving set. This effect is then transmitted to the diaphragm of the earphone or loud-speaker, making it vibrate and emit sound waves. At the transmission station the reverse happens. Sound waves, emitted by the person broad-casting, for example, make the diaphragm of the micro-phone vibrate. This diaphragm is connected with an electric circuit, and its vibrations are passed on to the current. Vibrations in the current—electric pulses they may be called—send out magnetic pulses in the ether. These are the wireless waves.

No radiation of wave-lengths between those of the



This table shows the relative sizes of various objects which we observe and measure. It is like a set of shelves on which we place specimens of objects which vary in size from the very great to the very small. On the middle shelf marked zero, we have the centimetre, and the thickness of a pencil to represent objects of that order of magnitude. On the shelf above we place an object of about ten centimetres in size; the width of a hand will serve. The shelf above takes objects of about a hundred centimetres, for example small objects of furniture. The width of a street will represent a thousand centimetres, the height of a tower might be ten thousand centimetres or a hundred metres, and so on. Below the zero shelf comes first a shelf holding something of a millimetre in thickness, as a card; then the hair's breadth on the next shelf and so on. Bacteria are at various heights on the third and fourth shelves down; molecules on the sixth and seventh, atoms nearly down to the eighth. On the other side of the vertical line the various wavelengths are shown against the objects to which they correspond. Distances are sometimes given in figures. The sun's distance is fifteen million million centimetres, or in symbols $1 \cdot 5 \times 10^{13}$. This goes therefore on the thirteenth shelf up.

(From *The Universe of Light*, by permission of Sir William Bragg.)

shortest wireless waves and the longest heat waves are known. There is a big gap in our knowledge of the greater spectrum here, but it will probably be filled up.

As it is, wireless waves are continually being made smaller and smaller. The new Micro-Ray, which has recently been put into use for sending messages about aeroplanes, has a wave-length of less than a centimetre. At the other end the spectrum is quite continuous and there is no gap to be filled. Certain rays, known as Cosmic rays, are receiving much attention at the present time. It appears that they are shorter than any waves so far investigated.

The discovery of this continuous series of waves is a very wonderful one. Still more so is the thought that the greater part of the world we live in is made up of these vibrations. Some scientists even suggest that the whole physical world may originate in them; but, perhaps, even if they decide that it does, it will not affect us very much!

CHAPTER XIV

Astronomy

I

IN the first part of this book we saw that the old conception of the Earth as centre of the Universe gave place, during the sixteenth and seventeenth centuries, to a new one. In the new doctrine the Earth was removed from its position of pre-eminence and relegated to one of comparative unimportance, becoming merely one of the planets which revolved round the Sun. In the new astronomy the Sun thus became the centre and most important heavenly body. Moreover, in the hands of Newton, the last of the giants who worked for the overthrow of the old system, the paths and motions of the planets were fully explored and the laws governing these motions established. In fact, from this time on, astronomers felt that they knew all about the Solar System.

In one respect, however, the old doctrine remained unchanged. The planets were still supposed to revolve against a spherical background containing the fixed stars; and the sun was, tacitly, assumed to be the centre of the whole universe. We have now to see how this assumption was, in its turn, to be proved to be quite unjustified.

Sir William Herschel (1738–1822).—The story of the exploration of the 'Fixed Stars' is a thrilling one, for it was carried out by a man quite untrained in Science and Mathematics who took to the study of the heavens purely as a hobby. William Herschel was born in 1738 in

Hanover. He was the son of a bandsman in the Hanoverian Guards, and followed his father in that profession. When he was about seventeen years old the Hanoverian Guards were called to England, for the Hanoverian Georges were now on the throne of this country. Two years later Herschel left the Guards, and after a number of musical positions in various towns in England settled finally in Bath as organist of the Octagon Chapel there. Bath at that time was a very fashionable place, and Herschel was soon drawn into the full swing of the musical life of the town. Besides holding the position of organist he taught a great number of pupils, and also wrote compositions of his own. Despite a hard day of about fourteen hours, however, he would spend half the night in various other kinds of study, such as Italian, Greek, Mathematics, and Optics. Then a book on astronomy came his way, and he turned with great zest to this new pursuit.

When he was about twenty-five his father died in Hanover, and Herschel suggested that a younger brother, Alexander, should come over to join him in England. The Herschels were a large family and all were musical; but Alexander was also very clever with his hands and, in this way, was to prove himself very useful to his brother. There was, also, a much younger sister, Caroline, who was devoted to her brother William, and he to her. Her mother was a firm believer in keeping her daughters well occupied with housework and needlework, and allowed them to have no other kind of education. For some time the two brothers in England made great efforts to get their mother to allow Caroline to join them, but it was not until seven years later that, finally, William succeeded in bringing her over to England.

Here she led a very different life, for not only did she do the housekeeping for her brothers, but she also herself had singing lessons and took her part in their musical life. This, still, was not all, for by this time Herschel was filled with the ambition to see for himself the wonders of which he read in his books on astronomy. He hired a small telescope, but was soon dissatisfied with it, and determined to make one for himself. The pattern used at that time was the one designed by Newton, which is generally known as the reflecting telescope, for which a very large spherical mirror [1] was required.

The Herschels' house now was turned upside down and filled with tools and polishers of all sorts with which the two brothers proposed to make the telescope. At the same time, they had to carry on with all their musical work. Their time was so crowded that it even came to Caroline having to feed her brother while he ground and polished his mirrors! Finally, however, in 1774, when he was thirty-six years old, Herschel finished his first 5½-foot telescope, and began viewing the heavens with it. He at once started to make another telescope, however, and this was followed by still another larger one. In fact he was never satisfied. His ambition was to make a 20-foot instrument.

With his first telescope he began a systematic survey of the heavens; what is technically called 'sweeping' them. This is a very slow and tedious business, for every bit of the sky has to be examined with the utmost care. Each individual star has to be noted, described, and its exact position ascertained. During his lifetime

[1] A spherical mirror may be conceived as a slice cut off a hollow sphere. The reflecting surface may be either the inner or the outer, *i.e.* the mirror may be concave or convex. In this case the mirror was concave.

Herschel carried out this operation, passing the whole of the heavens under review four distinct times!

He soon began to find out some new and extremely interesting things. Even with the naked eye, of course, it can be seen that the stars are not all of the same brightness. With his powerful telescope Herschel discovered many more differences. Some stars he found were 'variable' in their brightness. Again, stars differed from each other in their colour. Most interesting of all, he found that many were really 'double,' two stars revolving round each other.

In some parts of the sky he found what he called 'nebulæ.' These were bright luminous patches in the sky. He found it difficult to explain these, and so did other astronomers when they saw them. (See Plate XVIII.)

He began writing about all these discoveries, and in this way built up a considerable reputation.

In 1781, however, he discovered something which immediately made him really famous. This was a new planet! How did he know it was a planet? Chiefly by its size, because it appeared to be so much bigger than the other stars. This meant that it was much nearer. Then, also, its position continually altered with reference to the others. At first he thought it was a comet, in which case it would move in a very long ellipse and vanish from sight for a considerable period.

Directly they heard of the discovery professional astronomers turned their telescopes on the star, and set to work to calculate its path or orbit. This, they found, was almost a circle round the sun. It was therefore a new planet; more than a hundred times as big as the earth and nearly twice as far away from the sun as Saturn, the outermost of the other planets. This was, indeed, a startling

discovery. For centuries the number of planets had been taken as one of the fixed things of nature and of special significance.

The new planet was called Uranus, and it and its discoverer became the talk of the day. The King, George III, sent for Herschel and his telescope to Windsor to show the Court the new planet. The Astronomer Royal, on seeing the telescope, declared that the one at Greenwich was not to be compared with it. Finally, the King appointed Herschel to be astronomer and telescope-maker to himself, and Caroline was sent for to set up house near Windsor.

So many people wanted telescopes that Herschel soon wearied of making them, for he got no time for his own observations, nor to make a better instrument for himself. The King heard of this, and ordered that a gigantic telescope be made for Herschel's own use. This was done, and a wonderful instrument, costing finally £4000, was built. (See Plate XVIII.) With this he continued his careful study of the heavens. His sister, Caroline, spent more time than ever helping him, taking down observations and also making discoveries with a telescope of her own. Even when Herschel married and she removed into lodgings she still came across every night to help with the observations. The telescope was erected outside, and they worked every clear night, even when the temperature was many degrees below freezing-point. Night was turned into day. Luckily they both seemed to have very good constitutions, for Herschel lived to be eighty-four and Caroline to be ninety-eight!

Herschel continued to make discoveries. During his lifetime he discovered 806 double stars and 2500 nebulæ. He found that, after all, the stars are not fixed, but move

slowly among themselves, and he measured this motion. He realised that the sun of our solar system is but one among many such. The solar system, indeed, is a mere speck in a universe, almost vaster than mind can conceive. Moreover, the sun is by no means one of the biggest stars. Sirius is twenty times larger. Further, he found that even the sun is not fixed, but is moving rapidly through the heavens.

One thing he tried hard to do but failed in. This was to measure the vast distances between the stars. This, as we shall see, was done later. Even so, his achievement was tremendous. He had shown that what, to the naked eye, looked like a flat background on which were painted at intervals fixed luminous points was, in reality, a vast space through which were moving, probably at tremendous speeds, myriads of stars compared with which our sun, with its satellite planets, shrank into insignificance. This Herschel achieved by dint of unlimited enthusiasm, unlimited energy, and unlimited patience. Nor must we forget the loyalty, zeal, and enthusiasm of his indefatigable sister, Caroline. Such a pair is not often to be met with in the annals of history.

Laplace (1749–1827).—Contemporary with Herschel, although born some ten years later, was a very clever French mathematician and astronomer named Laplace. He belonged to that extraordinarily brilliant group of French scientists that characterised the era of Napoleon Bonaparte and the years immediately succeeding it. He was essentially a mathematician. He continued Newton's work in calculating the effect of the various planets on each other, for Newton's Law of Gravitation applies not only to the attraction existing between the planets and the sun, but also to that between the planets themselves.

The forces in the latter cases are, of course, smaller. But they are none the less important, for small forces continually exerted may have great consequences.

There was a question, raised by Newton himself, as to whether the solar system was quite stable. That is, would the planets always move in just the same way, or would they get nearer or farther away from the sun? If the former, it might happen that one of them would eventually fall into the sun, in which case the heat developed would be so tremendous that it would be the end of life on this planet at any rate.

Another astronomer, named Halley, who was contemporary with Newton, had searched old documents and star-maps from the very earliest times for the positions of the various planets and the times of eclipse of the moon. It was quite possible from the Law of Gravitation and the known positions of the planets at the time (*i.e.* Newton's and Halley's time) to calculate where the planets should have been at the time given in the old maps; and when each eclipse should have occurred. This was done, but the results did not agree with those recorded.

Laplace, however, attacked the problem with the help of another mathematician, Lagrange. These two were able to show that the disagreement was due to the fact that the effect of the planets on each other was not allowed for in calculating the early positions. When this was done there was good agreement. Furthermore, Laplace was able to show that although the paths of the planets round the sun have quite definitely changed during the thousands of years over which records have been made, yet the changes have been rather like the swings of a pendulum, sometimes towards and sometimes away from the sun. There is no danger of the planets falling in on the sun and

destroying the solar system, as things are at present. We express this fact by saying that the solar system is 'in equilibrium.' Of course, if anything from outside were to upset it, that would be a different matter.

In considering the solar system, Laplace was struck by some rather extraordinary coincidences.

Firstly, the direction in which the planets were moving round the sun was the same in every case. Moreover, the satellites each moved round their own planet in this same direction. Secondly, the orbits of the planets and their satellites were all in very nearly the same plane. By that is meant, that if the plane of the ellipse in which the earth moves were extended indefinitely, it would be found to include also the paths of the rest of the planets round the sun, of the moon round the earth, of the moons round Jupiter, and of the rings round Saturn.

Pondering on this, Laplace came to the conclusion that at one time the sun and the planets, and their moons, must all have been part of one gigantic mass rotating in the same direction. If this were the case, however, the matter of which they consisted must have been very much rarefied—that is, spread out, for the solar system occupies a tremendous space compared with the masses of the sun and planets to-day. This matter must, therefore, have been in the gaseous state.

By this time Herschel had begun to make his discoveries of the nebulæ in the heavens, and astronomers had come to the conclusion that they were just such masses of rotating gas. Laplace, therefore, suggested that the solar system had originally been one of these glowing gaseous nebulæ rotating in space. By now, also, physics had so far advanced that it could be shown that such a rotating mass of vapour, as it cooled, would shrink and separate on

the outside into rings which would go on rotating with the central mass. As these rings cooled they would divide into fragments, which later would probably collide and form one mass which would still go on rotating. The smaller of these masses would cool quickly and become first liquid and then solid, while the larger masses would retain their heat longer. The central mass, of course, formed the sun, and the outer rings shrank and coalesced to form the planets.

This theory is always known as Laplace's Nebular Hypothesis, and was held to be the probable explanation of the origin of the solar system for more than a century. Recently, however, another explanation has been put forward, which is more in accordance with the wider knowledge of the present day. The origin of the solar system, and indeed of all stars, is still supposed to be one of the nebulæ. In course of time these nebulæ gradually condense and cool as they revolve, and usually they eventually divide into two halves, which go on revolving round each other, forming one of Herschel's 'double stars.' An accident, however, happened to the star which is our sun. Herschel had found, you remember, that the stars are not fixed but are moving through space. The distances between the stars are so vast that they rarely come near enough to have any effect on each other; but in the case of our sun it is supposed that such a thing did happen. Some other star, in its journey through space, approached our sun so closely that the attraction between the two masses tore great chunks out of the sun. These masses were carried on round with the central mass left, and so formed the planets. This is the explanation held to-day.

The Discovery of Neptune.—After the discovery of

Uranus by Herschel, astronomers began to wonder whether this planet had really previously been seen by any other observer, but not recognised as differing from the fixed stars among which it moved. Accordingly the maps of various earlier astronomers were searched. The object was to see whether they recorded the position of any star agreeing in brightness and magnitude with Uranus, which was not in that position now. In this way it was found that Uranus had been seen and catalogued altogether twenty times! But no one had exercised the care that Herschel had used in comparing observations taken at different times. So Uranus had never been recognised as a planet.

These older records were now useful in finding, or 'computing' as it is called, the exact path of this new planet. After a time it was found that it did not travel exactly the path calculated by the Law of Gravity. The calculations took into account the effect of the other planets as well as that of the sun. Here was a new problem for astronomers to solve.

Two explanations were suggested. One was that Newton's Law of Gravity was after all not exact and that Uranus only obeyed it approximately. The second was that, somewhere, there was another large body, probably another planet, farther away from the sun, which was pulling Uranus slightly out of its path. This last explanation was all very well, but the puzzle was where to look amongst all the vastness of the sky for this unknown planet. But found the planet was; and its finding was one of the greatest achievements of mathematics.

John Adams.—The man who first showed where it was to be seen was a young Cambridge graduate, Senior Wrangler of his year. That is, he headed the list in the

examination for the Mathematical Tripos in the university. His name was John Adams. Fresh from the victory, he set himself the task of solving the problem of the 'perturbations' of Uranus.

It was a mathematical problem, the like of which had never before been attempted. Here was Uranus being pulled out of its path by an absolutely invisible agent, and Adams had got to find the size and whereabouts of the latter just with a pencil and paper. Well, he did it. Then he wrote to the Astronomer Royal and told him that if he pointed his telescope at such and such a point in the sky, at such and such a time, he would see the new planet which was upsetting Uranus.

It might be expected that the Astronomer Royal would have been very interested in this information to the exclusion of everything else. But he was constantly getting letters telling of wonderful new discoveries, nearly all of which proved to have nothing in them. Besides, Adams was a very young man. So all the Astronomer Royal did was to write to Adams and ask him if his new planet would explain something else which was not quite understood. Unfortunately, Adams did not bother to answer this question, and so nothing more was done about his discovery.

In the meantime, a young French astronomer, Leverrier, was at work on the same problem, and he also solved it successfully. Eight months after receiving Adams' letter, the same Astronomer Royal of England received a letter from this Frenchman, Leverrier, giving a position for the new planet within 1° of that given by Adams. After all, he thought, there must be something in it. However, he put the same question to Leverrier as he had to Adams, and this time, since it was answered

promptly and satisfactorily, he decided to search for the planet.

His telescope, however, was occupied in other ways, so he wrote to the professor at the Cambridge Observatory asking him to make the search instead. A steady sweep of the heavens in the direction advised was then started and all stars of the right magnitude noted. To make sure, however, that they found the right star, it was really necessary to compare their observations with a good star map. If they found something which was not on the star map, then this would be the new planet which, of course, has no fixed position. Unfortunately there was no such map at Cambridge.

In the meantime, Leverrier had also communicated with the observatory at Berlin, where a first-rate map of the heavens had just been completed. The head of this observatory pointed his telescope in the direction advised by Leverrier, and with the aid of his map was at once able to pick out the new planet, which was not a mere point like the other stars, but appeared as a small disc. The news of the discovery travelled quickly over Europe, and England realised that she had lost the race. If all concerned had been a little more alert, from John Adams to the Astronomer Royal, or the professor at Cambridge, the honour of the discovery might have been theirs.

However, the world nowadays honours Mr Adams for his real priority, though, as his papers had not been published, he could not claim this officially. Luckily, his was the character to take the disappointment in a generous manner and so save one of those unseemly disputes which, alas, have sometimes arisen in similar circumstances!

The new planet was called Neptune, and was found to take third place among the others in size. It is quite invisible to the naked eye, although Uranus may be seen by any one with good sight knowing where to look. Uranus takes eighty-four years to revolve round the sun, while the time of one revolution by Neptune is one hundred and sixty-four years, nearly twice as long. When the path of Neptune was well established it was found, as with Uranus, that there was a discrepancy between this observed path and the one calculated. Accordingly yet another planet was searched for by the methods of Adams and Leverrier. In 1930 it was thought that this planet had been located from the Mount Wilson Observatory in America. Further investigations showed, however, that though this new star, since named Pluto, undoubtedly is a planet, it is not nearly large enough to account for the deviation of Neptune from its calculated path. The search must, therefore, still go on.

II

We must now go back in time and see how gradually our knowledge of the heavens increased. This knowledge was not only of the positions of the various stars but of the distances between us and them; of the rates at and directions in which they move; and even of the matter of which they are composed. Now, all the knowledge we have of the heavens comes to us in one way only—by means of light. If there were no light, or if we could not perceive it, the heavens, as far as we are concerned, might not exist. As our knowledge concerning light itself advanced, therefore, so did our knowledge of the sun and stars from which the light comes.

The Speed of Light.—One of the oldest problems concerned the rate at which light travelled. It obviously travelled exceedingly quickly, but did it really take time to do so? The first man to attack the problem experimentally was Galileo, who arranged men with lanterns on opposite hills to signal backwards and forwards, each showing his light immediately he saw the other's. As the men grew practised in responding, the time diminished until there was no reason to suppose there was an interval at all. We now know that such an experiment carried out on this earth is bound to fail, because the distances are too small. Not unless the distance across which the light was sent was very great indeed, or unless the means of flashing the light and measuring the time were far more exact, could the experiment have succeeded.

Olaus Roemer.—It was a young Danish Astronomer, Olaus Roemer, who saw how the speed of light might be found by letting a star signal to the earth over the great distance between. The star he used was one of the moons of Jupiter which had first been seen by Galileo through his telescope.[1] Periodically these moons, in revolving round Jupiter, pass behind the latter into the cone of shadow cast by the sun. We say there is an eclipse of the particular moon under observation.

Now the moons move at constant speed, and therefore these eclipses should occur at regular intervals. Roemer observed the eclipses carefully and found this was not the case. At certain times the eclipses were early and at others late, the variation being a maximum of about eight minutes each way. Roemer came to the conclusion that the explanation of this difference was

[1] The word 'star' is used here in a general sense. Strictly speaking, Jupiter's moons are not stars, as they are not self-luminous.

that light did take a definite time to travel. At certain times of the year Jupiter and the earth are on the same side of the sun, when an eclipse of one of Jupiter's moons occurs. In this case, the light will have the shortest distance to travel to the earth. The eclipse will, therefore, *be seen* to take place before the time calculated from

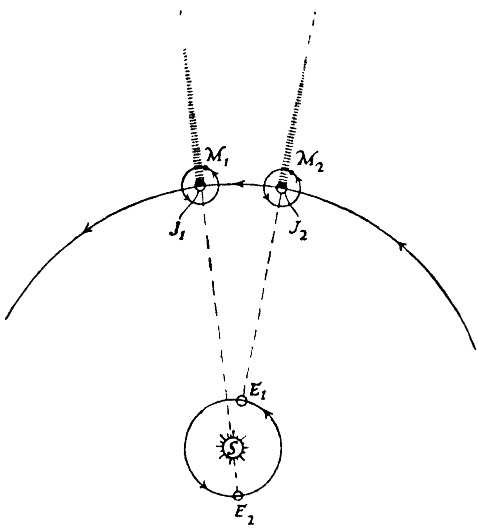


FIG. 37.—Illustrating two eclipses of one of Jupiter's moons (M_1 and M_2). The earth is shown in two positions (E_1 and E_2)

the average of all the intervals. When the earth is right away from Jupiter on the opposite side of the sun, however, the light will have to travel much farther to reach the earth. The extra distance will be that of the diameter of the earth's orbit, which Roemer knew to be approximately one hundred and eighty-six million (186,000,000) miles. Since there was a difference of sixteen minutes between the shortest and the longest intervals between the observed eclipses he argued that

it must take the light sixteen minutes (approximately 1000 seconds) to travel the one hundred and eighty-six million miles across the earth's orbit. This would make the speed of light one hundred and eighty-six thousand miles per second. This is certainly a tremendous speed, but it is what we call 'finite,' not infinite—that is, light does *not* travel instantaneously.

During the last century a very beautiful experiment to determine the velocity of light was carried out by a Frenchman named Fizeau. This was comparable to Galileo's experiment in that it was carried out on the earth's surface and an artificial source of light was used. By the nineteenth century, however, instruments had been perfected to such an extent that it was possible to carry out the whole experiment mechanically and to measure absolutely accurately very short intervals of time. The details of the experiment are too difficult to follow here, but it is interesting to note that Fizeau confirmed Roemer's approximate value, at the same time determining the velocity with much greater precision. The figure, 186,000 miles, or 300,000 kilometres, per second, is near enough for us to remember.

The Distances of the Stars.—One of the earliest men who attempted to measure the distances of the sun and moon from the earth was Hipparchus of Nicea, a Greek living in the second century B.C., about one hundred years after Archimedes. By this time the science of Geometry was well advanced, and Hipparchus was able to bring this to his aid in making his calculations. The only measurements which he made were of angles subtended by these heavenly bodies from points on the earth at different times of the year. In the hands of the Arabs astronomical instruments were very greatly

improved, and in the time of Galileo and Newton the measurement of such distances as those of the diameter of the earth's orbit, and the distance from the earth of the moon, sun, and the planets, offered little difficulty. We cannot here go into the method used; but, if you are interested and can get hold of Sir William Bragg's book called *The Universe of Light*, you will find that, on p. 200, he explains, as simply as is possible, how these measurements are made.

Herschel attempted to apply these same methods in finding the distances of the fixed stars, but he failed, because the stars are so very much farther away from us than the sun and the planets. In 1838 a German named Bessel, with the aid of a very beautifully designed instrument called a heliometer, succeeded where Herschel had failed. From thenceforward, knowledge concerning the distances of the stars from the earth, and from each other, gradually accumulated.

Compared with the kind of distances with which we deal on this earth, the distance away of the sun is very great. It is ninety-three million miles. The average distance from the sun of the outermost planet, Neptune, is two thousand eight hundred million miles. If these distances are small compared with those of the fixed stars from the earth, it is at once apparent that the latter must be very great indeed. The nearest star to us is about four hundred thousand times farther away than the sun. Others are so far away that it is still impossible to measure their distance. It is obvious that the mile, which is a unit chosen for use on our pigmy earth, becomes absurdly small when used to measure these distances. Accordingly, astronomers have chosen a new unit. This is the distance travelled by light in one year; and this they

call a 'light-year.' Since light travels one hundred and eighty-six thousand miles *per second*, the distance it travels in a year must be $186{,}000 \times 60 \times 60 \times 24 \times 365$ miles. This comes to over five billion miles!

The nearest star is just over four light-years away. This means that the light by which we see this star to-day started on its journey to us four years ago, while light from the farthest stars started centuries ago. Our news of the heavens is, therefore, a trifle behind the times, but it is the best we can get!

III

Spectrum Analysis

The Composition of the Sun and Stars.—By investigating the kind of light which comes from the sun or any particular star, we are now able to find out what chemical elements are present in the matter of which it is composed. To follow this process you must be quite sure that you understand that a ray of light is really a train of waves through the ether, and that the only difference between different coloured lights is in the size of these waves. You know that when white light is passed through a prism a band of colours in a definite order is obtained, called a spectrum. The wave-length of the light forming a spectrum decreases regularly from the red end to the violet end, and there is a definite wave-length corresponding to each part of the spectrum. If this is well understood, what comes next should follow quite easily.

Josef Fraunhofer (1787–1826).—The splendid telescope, called a heliometer, with which Bessel was first able to measure distances among the fixed stars, was made for him by a very clever young workman called Fraunhofer.

This young man had been apprenticed to a mirror-maker very early, since he was an orphan. While working for this master the house collapsed and buried Fraunhofer in the ruins, from which, fortunately, he was rescued alive. His miraculous escape attracted the interest of the Prince of Bavaria, and his poverty and ill-health so excited the Prince's sympathy that the latter gave him a handsome present of money. With this Fraunhofer bought his freedom from his master and also bought books and learnt engraving on metal. A few years later he entered some large optical works and soon became famous for the instruments he made. His most important achievement was a great improvement in the manufacture of glass, which enabled far more precise results to be obtained with lenses, mirrors, and prisms made of it.

Fraunhofer himself made a very important discovery with a prism made of this improved glass. He was able to get with it a very beautiful and clear spectrum, using the sun's light. In this spectrum he found something which Newton, with his inferior prism, had missed. Instead of the colours being continuous from one end to the other, he saw that the spectrum was crossed at intervals by a number of dark lines. He observed these dark lines on many different occasions, and every time he found that the lines were in exactly the same places.

Next, he used the light coming from Venus to make a spectrum, and again he found the dark lines. There were also lines in the light from certain fixed stars, but these were rather differently grouped. He made very careful drawings of all these spectra and numbered and lettered the lines. Forty-five years later, when two German professors found out what was the cause of these lines, Fraunhofer's careful records were a great help to them.

Bunsen and Kirchoff.—These two professors worked at the University of Heidelberg. They also were investigating different kinds of spectra. Each of them made a very important discovery, and the two discoveries together explained the dark lines in the sun's spectrum which now are always known as the Fraunhofer lines.

Bunsen discovered that when the *vapour* of a substance is made to glow, the light from it, if passed through a prism, does not show all the colours given by white light but only certain coloured lines with dark spaces in between. For instance, if the metal sodium is heated in a flame, the flame gives out yellow light, which, on passing through a prism, gives two narrow yellow lines, which are always in the same place. Other elements give many more lines of other colours, but the same element always gives exactly the same lines, no matter with what else it is mixed.

Bunsen saw that this was a very good way of finding out whether any element was present in a substance. All that had to be done was to turn the substance into vapour by holding it in a hot flame and look at the flame through a prism, or rather a specially designed instrument containing a prism, called a spectrometer. If the lines characteristic of the element were seen, then that element was known certainly to be contained in the substance. It was to get a clean hot flame for vaporising substances that Bunsen invented his famous 'Bunsen burner.'

These special spectra by which the elements can be identified are only given by gases. Let us see what sort of light is given out by hot solids and liquids. Suppose an iron ball is gradually heated so that it begins to glow. The colour, as you know, changes from a dull red to a bright red, which gets more and more yellow until finally the ball is white hot. If the rays coming from the ball

are sent through a spectroscope, it can be shown that, at first, they consist almost entirely of radiant heat waves. These, you remember, are the next in size to waves of red light. They cannot, of course, be seen with the eye, but there are instruments which will detect them. As the ball gets hotter, red light begins to appear, then orange and yellow, and so on, right through the spectrum, until all the colours are there. At this point the ball, when looked at directly, appears white. The individual colours can only be seen by separating them with a prism. Light from intensely hot solids then gives a complete continuous spectrum. It is not correct to say that the sun is exactly solid; but the matter in the centre is so closely packed together that the elements are not able to give out their own individual spectra as they can in the rarefied gaseous state. We can take it, therefore, that white light comes from the interior of the sun.

Now we come to Kirchoff's discovery. It will be best explained by describing one of the experiments he did. First of all he obtained a very bright source of white light which gave a continuous spectrum with no dark bands when passed through a prism. Then he placed, between the light and the prism, a flame coloured yellow with sodium, like the one Bunsen used. On examining the spectrum now, he found that there were two black lines in it in exactly the same position as the bright lines which Bunsen had got when he used the sodium flame alone. Let us now see what Kirchoff learnt from this.

Where the black lines were, obviously no light was falling. There was light falling there before the sodium flame was introduced, because the white light gave a continuous spectrum. The only explanation was that the sodium flame had absorbed the light of those particular

wave-lengths. But these were the waves which the sodium flame by itself sent out. It would seem, therefore, that if white light falls on a glowing gas the elements in that gas pick out and retain their own characteristic kind of light, but let all the rest pass on. Kirchoff proved that this was so by using many other elements besides sodium. He always found that the kind of light which was ordinarily sent out by the element was taken away from the white light.

Perhaps you have seen by now how helpful that discovery was in explaining Fraunhofer's lines in the spectrum of sunlight. As we have seen, the centre of the sun gives out white light because it is very hot and very dense. Round the outside, however, the atoms are not nearly so closely squashed together, and are really in the gaseous state. So we have white light coming to us through the envelope of glowing vapour round the sun. The elements in this vapour absorb their particular kinds of light so that, when it reaches the earth and is passed through a prism, Fraunhofer's black lines are seen.

Fraunhofer had measured the position of these lines very carefully. Bunsen had found the positions of the characteristic lines of nearly all the elements found on the earth. Nearly all the black lines corresponded with elements known on the earth, and so, in this way, the material of which the sun is made was analysed into its chemical elements. Remembering that the sun is ninety-three million miles away, that was really something of an achievement!

There was one element detected in the sun which was not discovered on earth until some years afterwards. That was the element Helium, whose name means 'the sun.' You probably know that this is a light non-

inflammable gas used in airships. So far, no element has been discovered in the sun or in any of the stars which is not known on earth. The whole universe is, therefore, composed of just the same 'stuff.'

The Temperature of the Stars.—We saw that as the temperature of a solid, such as an iron ball, is raised it begins to give out light of shorter and shorter wave-lengths. It is possible, by examining the spectrum of light given out by a star, to calculate its temperature. This is done by seeing in which part of the spectrum the light is most intense. The shorter the wave-length of the most intense part the higher is the temperature of the star from which the light is coming. If you look at the stars on a clear night you will see that some seem to give a bluish light, while others are definitely orange. The blue stars are the hottest stars of all.

Motions of the Stars.—It is also possible to tell from the spectrum of a star whether it is approaching or retreating from the earth. I am not going to attempt to tell you how this is done. A curious fact has been found out, however, in this way. It seems probable that the very far-off nebulæ are all rushing outwards away from us and from each other at a tremendous pace; in fact, that there is a general outward expanding movement of all the stars and nebulæ of the universe. We shall have a little more to say about the universe in the last chapter of all.

CHAPTER XV

Biology

I

The Scope of Biology.—Biology is a word which has only come into general use comparatively recently. It means 'the study of living things,' and includes the sciences known as Botany, the study of plants; Zoology, the study of animals; Physiology, the study of the human body; and Psychology, the study of the human mind. Psychology is the newest of all these branches and the most difficult. We shall not have anything to say about it here.

It has taken men much longer to learn about living things than about the rest of the physical world. One reason for this is that they have to take living things more or less as they find them and cannot very easily stage experiments to show just the one thing which they want to know. In Physics it is generally possible to think out an experiment in advance and arrange that nothing shall interfere with the particular event that is being studied. In dealing with living things, however, this is not possible.

Another reason is that man has embedded in him a great reverence for life. So we find a reluctance to take the life of animals, or to use the body of the dead in the search after knowledge. Lately, however, this reluctance has been overcome by the recognition that the welfare of future generations is at stake.

Aristotle.—The early study of life was almost always connected with the study of medicine. Aristotle was

the first man we know of certainly who studied all kinds of living creatures and wrote about them. His writings, however, deal not only with what he discovered for himself, but also with what men long before him had found out and written down in books of which there is now no trace.

There are two ways of studying living things. In Anatomy we deal with their structure. It is comparatively easy to study, as it can be carried on with creatures after they are dead. They can be dissected and the various parts examined. But to know all about the parts and organs of a creature when it is dead is not to know how those parts and organs function when the creature is alive. This knowledge is sought for in the study of Physiology, and is much more difficult to gain.

Galen (A.D. 130–200).—The old doctors were, of course, interested in the anatomy of the human body, but it was not easy to study this. For a time, in Alexandria, the law allowed the bodies of criminals to be used for the purpose, but, for the most part, such a thing was rarely done. Instead, men dissected the corpses of the higher animals, chiefly apes and dogs; and supposed that human bodies were very similar. A certain Roman doctor, named Galen, collected together all the knowledge of anatomy gained in this way by his predecessors, and added many observations of his own. All this he wrote down in a book.

The important thing to remember about Galen is that his book became the great Authority for doctors in the Middle Ages. I hope, by now, you have realised what a tremendous part 'Authority' played in those times. During the dark ages, as we saw, men gave up the study of science altogether. When they again began to be

interested it was to the old writings that they turned and not to life itself. In the various universities that sprang up all over Europe the students working for their doctor's degree had to learn the books of Aristotle and Galen wholesale, and never did any finding out for themselves. Later, some attempt at demonstration was made at lectures, but the dissections were carried out by professional 'barbers,' as they were called, who probably did it so badly that it was quite impossible to see whether or not their results agreed with the teachings of Galen.

Vesalius (1514–1564).—In 1514, five years before Leonardo da Vinci died, there was born in Brussels a man who was to change all this. His name was Vesalius. He belonged to a cultured and learned family and many of his ancestors had been physicians. Very early in life he developed a passion for dissection, and, by practising on birds, rabbits, dogs, and all sorts of small animals, he soon acquired very great skill in it. He quite naturally decided to be a doctor and went to Paris to study and take his degree. From there he went to the University of Padua, in Italy, to be in charge of the Department of Anatomy. At first he did what everyone had always done, and taught his students straight out of Galen's book. He could not stand the clumsy work of the professional barbers, however, and very soon he took to doing his own dissections. This at once led to some remarkable discoveries. Remember that he was now dissecting human bodies, and that the writings of Galen, although *about* the human body, were based on the study of animals such as the ape and the dog. Galen said that there were three bones to the lower jaw. Vesalius only found one. Again, Galen said that the thigh bones

were curved, but Vesalius found that they were straight. Many other such contradictions were brought to light in this way, and in yet another instance the old pillar of Authority began to crumble and fall. In many cases the mistakes made by Galen were due to the fact that animals had been dissected instead of humans; but much error was also caused because he had included in his book all sorts of statements based on old superstitions and beliefs. For example, it was an old belief that man was a rib short on one side because woman was made from one of man's ribs. Vesalius, however, soon showed that there were just the same number each side!

These discoveries made a great stir in Padua. Not only was Vesalius a very skilled dissector but he had also a very lively and vigorous personality, and students flocked to hear his lectures. In this way the new generation of doctors learnt to dissect for themselves and to discard the old teachings of Galen.

Vesalius himself now set to work to study the human body very carefully, and at the end of five years published a book on its anatomy. This he dedicated to the Emperor Charles V. It was a most interesting book. Not only did it contain a great deal of new knowledge based on true observation, but it was also very beautifully illustrated with drawings of the structure of various parts of the body. These illustrations were done by a pupil of the famous Italian painter, Titian. If you have seen any portraits painted about this period you will remember that behind the figure there is always painted in an Italian landscape. Exactly the same thing was done in the illustrations to this book by Vesalius. Behind a great figure dissected, say to show the muscles of the back of the body, was to be seen a very beautiful landscape! The

whole book was remarkable both for its matter and for its production. (See Plate XIX.)

Vesalius may have been popular in the University of Padua, but the publication of his book soon made him unpopular outside of it. It was the same old story. The new discoveries trampled on the old and cherished beliefs, and the book was pronounced to be blasphemous. Vesalius was forced to leave Padua, but, luckily, was appointed Court Physician to Charles V and, after the latter's death, to Philip II of Spain. After nineteen years in this capacity, however, through some cause not certainly known, he fell from favour and had to leave Spain. He went on a voyage to Palestine, and, on the way home, his ship was wrecked. He was stranded on one of the Ionian islands, and there died from exposure. It is worth while to remember the name of Vesalius and what he did. His book laid the foundation of all modern biological science. He overthrew the old false god of Authority and founded a new tradition in the study of anatomy. He made errors, but these were soon corrected by his successors working according to the methods he had taught.

Meanwhile, there was still no certain knowledge about physiology or the working of the body. The current beliefs were, for the most part, those of Paracelsus who envisaged a kind of presiding demon superintending the various internal workings of the body. The first man to attempt to investigate any of these processes by experiment was an Englishman named William Harvey, who established as a fact what is now termed the 'Circulation of the Blood.'

Harvey (1578–1667).—William Harvey was born at Folkestone in 1578, in the reign of Queen Elizabeth.

PLATE XIX

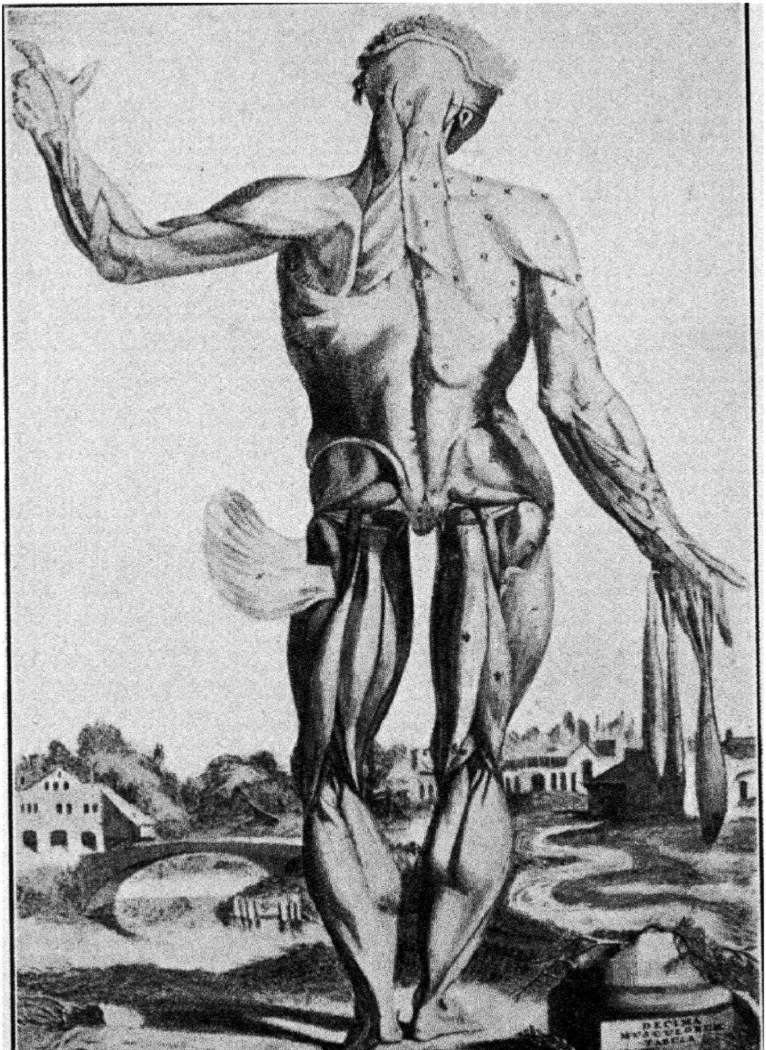


Illustration from Vesalius' book on Anatomy

(Drawn by a pupil of Titian)

As a boy he went to King's School, Canterbury, and afterwards to Caius College, Cambridge. From Cambridge he went to Padua and studied anatomy under a very famous professor named Fabricius. Harvey came to know Fabricius well, and was most interested in the discoveries the latter was making about the little doors or 'valves' in the veins. It was well known that there were two kinds of blood-vessels leading from the heart. There were the deep-seated arteries carrying very red blood which spurted out when the artery was cut, and the veins which were near the surface. At intervals the veins had these valves, which Fabricius was studying, and contained dark purple blood which oozed rather than spurted when the vein was cut. The arteries and the veins did not appear to meet anywhere in the body.

It was also known that the heart was divided into four chambers, two on the right and two on the left. The top chambers were called the auricles and the bottom the ventricles. Look at the diagram to understand this. There were quite clear openings from the auricles to the corresponding ventricles, but no apparent passage from one side of the heart to the other.

It was, of course, also well known that the heart and the arteries appear to beat—that is, the blood passes in pulses. Galen had explained this by supposing that there was a continual ebb and flow—that is, a backwards and forwards movement of the blood in both the arteries and the veins to and from the heart. He said that the dark blood in the veins was crude blood, while that in the arteries was mixed with vital spirits which made it bright and lively. He thought that there were tiny pores in the wall dividing the heart vertically, and through these pores some of the crude blood oozed from the right side

to the left, where it became charged with vital spirits. He also thought that some crude blood from the right

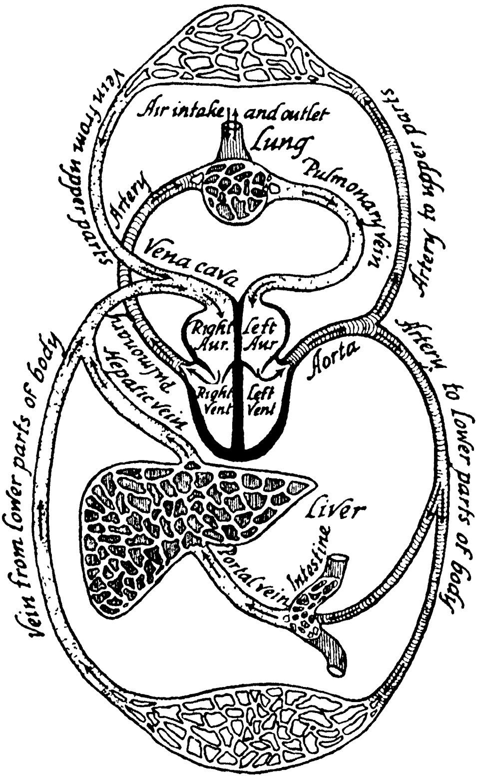


FIG. 38.—Diagram of the circulation of the blood
(From *The Discovery of the Circulation of the Blood*, by permission of Dr Singer.)

side travelled through the lungs to the left side. He was proved to be right in this last supposition.

The valves that Fabricius was investigating in the veins were rather like trap-doors which will only open one way. In this case they opened towards the heart. This fact interested Harvey very much, for it showed him that the

idea of the blood pulsing backwards and forwards in the veins was an impossible one. The blood could only move one way, towards the heart. Some other explanation of the movement of the blood must, therefore, be found. With this problem in his mind he left Padua and returned to England, where he soon became a very prosperous doctor and later on physician to King Charles I. At the same time he set about experimenting to see whether an idea which he had had was the right one. This was the idea.

Since the blood could only go towards the heart in the veins it had to come from somewhere. Might it not be that there really was some connection between the veins and the arteries, and that the blood went out from the heart through the arteries and back through the veins? The only alternate explanation would be that new blood was being made all the time. Harvey soon showed that this was not the case. By experimenting with animals he was able to show that the quantity of blood leaving the left side of the heart through the arteries in half an hour was *more* than the total amount of the blood in the body at any one time. The only possible explanation of this was that the blood was going round the body and coming back again. There is something very important to notice here. Harvey had begun to use measurement. We have already seen that whenever men begin to measure quantities in science then we get a sure and certain advance.

Harvey did not rest with this as the only proof of his theory. He next carried out experiments with what are known as ligatures. First he bound up the top of somebody's arm very tightly, so that both arteries and veins were closed up and no blood could pass through. The

pulse in the wrist stopped, and the hand became blue and cold because there was no blood flowing through it. Then he loosened the bandage a little and found that the veins on the arm and hand below the bandage began to swell and become knotted. This, he explained, was because the loosened bandage no longer compressed the arteries and blood flowed to the hand. The veins on the surface, however, were still compressed, and so, below the bandage, they became very full and swollen, as the blood was continually being pumped into them from the arteries and could not escape.

In this way Harvey showed that his idea had been right. The blood leaves the heart by the arteries and returns to it by the veins. He also showed that the heart itself is the pump which keeps the blood moving. The muscles round the heart contract and squeeze out the blood, then they relax and the heart dilates and fills up again. He further showed that Galen had been right in thinking that the blood goes from the right side of the heart to the left by way of the lungs, but quite wrong in saying that some oozes through the division down the middle. The arrows in the diagram will show you quite clearly the path of the blood round the body. Harvey never actually saw the blood passing from the arteries to the veins through the tiny vessels which we call capillaries. When microscopes came into use this was quite clearly seen, as we shall hear.

In spite of the fact that he was physician to the unfortunate Charles I, Harvey died quite a wealthy and prosperous man. He was with the King during the first part of the Civil War, but he had no taste for war and was glad to be persuaded by his brothers, who were wealthy London business men, to leave the fighting and settle

down. They had, meanwhile, looked after his money for him, and so he was quite comfortably off. When he died, in 1667, he left his money to the College of Physicians in London. There is a portrait of him there and also one in the National Portrait Gallery.

Harvey's discovery of the circulation of the blood is the only one in physiology which we can describe in detail. After Priestley's discovery of oxygen and Lavoisier's experiments on the part played by oxygen in the air, the process of respiration was fully investigated. It was found that the red colour of the blood in the arteries was due to the oxygen which was absorbed as the blood passed from the right to the left side of the heart through the lungs. As the blood reaches the different parts of the body it gradually loses this oxygen and becomes dark in colour once again.

Müller (1774–1842).—As men's knowledge of chemistry and physics increased, so this knowledge was gradually applied to the understanding of various life processes. The man most famous for his investigations in physiology was a German professor named Johannes Müller, who lived from 1774–1842. In his laboratory at Berlin he and his students carried out many experiments and invented all sorts of apparatus for investigating the workings of the human body; and modern knowledge is based very largely on their results.

II

Discoveries with the Microscope

Now we must go back to the years immediately following Harvey's death and follow another path along which progress was made. The telescope, in the hands of

Galileo, brought the vast solar system within man's ken. The microscope was to open up yet another field of vision.

To whom should go the credit for the invention of the microscope is not certainly known, but at about the same time as the invention of the telescope it was found that lenses could be made which would make tiny things appear much larger. When these new microscopes were turned on living things, discoveries immediately began to be made. Three men stand out as making really important contributions to knowledge in this way. They are:

Marcello Malpighi—an Italian .	1628–1694
Jan Swammerdam—a Dutchman .	1637–1680
Anthony van Leeuwenhoek—also a Dutchman	1632–1723.

Marcello Malpighi was the son of a small landowner. He studied to be a doctor at the University of Bologna. After qualifying, he held successive posts at a number of the universities of northern Italy, and finally became physician to Pope Innocent XII. With the new microscope he examined all sorts of structures which hitherto, in the study of anatomy, could only be imperfectly seen. In this way he was able to examine the air-passages in the lungs and the tiny blood-vessels which Harvey had not been able to see for himself. He also saw the corpuscles in the blood which give it its colour; and the separate layers of the skin.

One of his most interesting bits of work was the study of the silkworm and the tracing of its life-history. With his microscope he was able to see the nerves, air-passages, and food canal in the insect, and to compare these parts with those in the better-known and larger animals. He

was also able to see the mechanism whereby the silk-worm forms the silk which makes it so valuable to man.

Lastly, he used his microscope to look below the surface in plants and described and made drawings of the structures which we now call cells.

Jan Swammerdam was born in Leyden. He was a wealthy man, who qualified also as a doctor, but devoted his time entirely to work with the microscope. His especial interest was the study of insects, and he became very clever at dissecting them under the microscope. If you think for a moment what this means you will realise that it requires a great deal of deftness and skill. In addition, Swammerdam made very beautiful drawings of what he saw. In this way he examined a number of insects, especially bees and mayflies. He also studied other small animals, such as snails and squids. Hitherto nothing was known about the anatomy of these small creatures, and our present knowledge of them is based largely on Swammerdam's work. All this meant looking through the microscope in a very bright light, which is a great strain and very trying. Swammerdam worked so hard and so incessantly that he completely wore himself out over it and died when he was still quite a young man.

Anthony van Leeuwenhoek was quite a different type of man from the other two we have heard about. He was not educated at a university, and lacked entirely any scientific training. Looking through the microscope was really a hobby for him, so that he did not devote himself to any one particular subject and try to find out all he could in a methodical manner. Instead, he worked in a very haphazard fashion, looking at any and everything which suggested itself to him.

Little is known about his early life, except that he was

born and lived at Delft in Holland. It is probable that he kept some sort of a shop, but it is quite certain that, for the latter part of his life, the shop took up little of his time.

Anthony van Leeuwenhoek not only used microscopes but made them for himself. There were two kinds of microscopes in use then; one sort had two lenses, one at each end of a short tube. This kind was like our modern microscope. The other consisted of only one very thick lens which had to be placed very near the object to be viewed. We now call such a lens a magnifying glass. Leeuwenhoek not only ground his own lenses but also made metal holders to contain the lens and fix the object in the right position. These holders differed according to what he wanted to look at. One sort was made to clamp a test-tube firmly just in front of the lens, so that liquids could be examined (Plate XX); and there were many other kinds. For a long time the Royal Society in London had a set of these microscopes which Leeuwenhoek had given them. Unfortunately, some time during the eighteenth century these were borrowed and never returned, and so a very valuable possession was lost.

As already stated, Leeuwenhoek examined a great variety of things under the microscope. He wrote about his discoveries in a very rambling and discursive manner. One of the most interesting things to remember about him is that he actually saw the tiny capillary blood-vessels linking the arteries with the veins. Harvey knew that these, or something like them, must exist, but, lacking the microscope, he never saw them. Leeuwenhoek first saw them in the thin transparent part of a tadpole's tail which he had in a test-tube.

One day he put some pond water in a tube and looked at it through his microscope. To the naked eye it was

just muddy water. To his amazement, however, on looking through the lens he found that it was full of tiny creatures moving up and down and all over the place. They were not all alike; some were red and some were green; some had forked tails which they lashed about; others had horns on their heads, or long streamers with which they churned the water; while still others looked like discs of floating jelly. Here was a whole new unsuspected world. These little creatures that Leeuwenhoek discovered are the simplest forms of living things. We now call them Protozoa. Leeuwenhoek found that, if the water dried up so that only the mud was left, these little creatures also dried up; but when water was again added, even after a year or two, they all 'came to life again,' and were as lively as before.

These are just two of the discoveries that Van Leeuwenhoek made with his microscope. He lived to a great age, and saw more new things, perhaps, than any man of his time. But he was not really such a good scientist as either Malpighi or Swammerdam.

The Cell Theory.—In the eighteenth and early nineteenth centuries the miscroscope was used more and more to study the structure of plants and animals. It was realised that different parts were made up of different tissues, and these tissues were classified and called by different names. Over and over again, however, the box-like structures which Malpighi had first described were seen to make up these tissues. They could be seen most clearly in plants, and seemed to consist of transparent walls containing, as a rule, a jelly-like substance. Later it was discovered that in the middle of the cell was a denser part of the jelly which was called the nucleus. Then cells were seen also in animal tissues and the nucleus also recognised.

In 1839 a German scientist named *Schwann*, a pupil of Johannes Müller the physiologist, published a theory about the structure of all living things which became known as the Cell Theory. He said that he had come

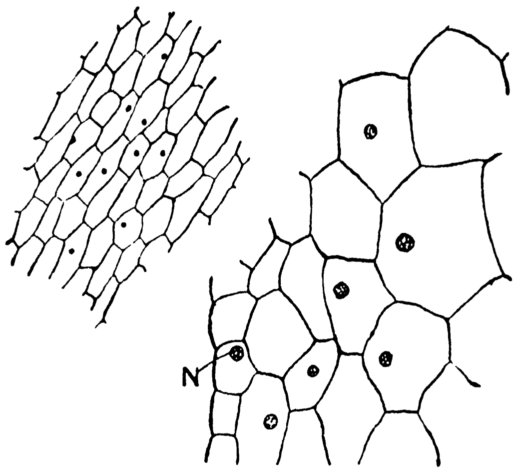


FIG. 39.—Surface view and section of a piece of onion skin showing nuclei (N)

(From *An Introduction to the Structure and Reproduction of Plants*, by permission of F. E. Fritsch, F.R.S., and E. J. Salisbury, F.R.S.)

to the conclusion that all living things, both plants and animals, were made up entirely of cells, just as a house is built of bricks or a chemical substance is built of atoms.

Schwann thought that the most important thing about the cell was its wall, but in this he was proved to be wrong. It was found that the cells in some animal tissues have no walls at all; and in 1861 another German, Max Schultze, showed that the really important part of the cell was the jelly-like material it contained with the denser nucleus in the middle. This material he called protoplasm, and it is the living material of both plants

and animals. The chemists were able to show that this protoplasm contained definite chemical elements, but no one had yet been able to manufacture it from those elements. In it are bound up all the mysteries of life. The dense region called the nucleus proved to be the most important and interesting part of all, since in it are known to be carried those characteristics which are inherited by one generation from the last.

How did this protoplasm come to be formed? At one time we know that there was no life on earth. Then one day there was. How did it happen? That is still an unanswered question. We do not know how the first life appeared on earth, but we do now know how the many forms of life which still appear to spring from nowhere originate. It is the story of this discovery which must now be told. It was a most important discovery, for it has had very far-reaching and beneficial effects on humanity.

It has long been known that if living matter, such as meat, is allowed to decay, before long it will become alive with maggots. Cheese or bread left about soon grows upon itself a mould. The old explanation of this was that life springs spontaneously from dirt, dust, and decaying matter. Frogs and toads were supposed to come from the mud of ponds, rats from the River Nile, and so on.

Redi.—It was an Italian, Redi, who in 1668 first thought of devising experiments to see if this view was, after all, the correct one. He placed some meat in wide-mouthed flasks; some of these he left open, others he covered with paper, and still others with a very fine net. The meat in all the flasks decayed and flies were attracted by the smell. In the open flasks the usual crop of maggots appeared, but not so in those covered with paper. In

the case of the flasks covered with netting it was found that the flies had laid eggs on the netting and these hatched out into maggots. So the maggots had come from the flies: life from life, not life from dirt.

Redi made other similar experiments, and finally came to the conclusion that in all cases where life apparently springs from dead matter, what has happened is that germs of life have been introduced in some way from without. In most cases these germs are too small to be seen with the naked eye, although the flies' eggs could have been seen if looked for. Leeuwenhoek saw some of these germs, even smaller than the protozoa, in his pond water; so small that even under the microscope they looked just like tiny black specks.

The next advance was when scientists found out that it was these germs or bacteria which cause organic matter—that is, matter which has been produced by living organisms—to decay. They also found that, if all air is excluded, the material will keep fresh, because the germs come from the air. That is, of course, the principle on which all modern 'tinned' foods keep fresh. The food is generally heated to a definite temperature, to kill all germs which might be in contact with it, and then sealed down so that the tin is absolutely air-tight.

It is not very easy to be quite sure that all the germs are killed, and all air excluded, and so it sometimes happened that experiments made with food, in this way, failed. That is to say, although it was thought all the germs must have been killed, and no air allowed to get to the food, yet the latter, in some cases, still went bad. When this happened, the man who did the experiment generally said that after all Redi and the others had been wrong, and that life could spring out of nothing.

Louis Pasteur (1822–1895).—The man who finally settled the question once and for all was the famous Louis Pasteur. Just over twenty-five years ago, a popular French magazine arranged for its readers to vote for the man whom they considered should take first rank as a prominent Frenchman of the nineteenth century. Fifteen million people voted altogether, and Pasteur won most votes. He received a hundred thousand more than the second on the list, who was Victor Hugo, the popular writer. Since he was considered such a great man, we must go rather fully into the story of his life and work.

Louis Pasteur was born in 1822 away in the east of France, near the Jura mountains. His father was a tanner, but had been a soldier in Napoleon's army. Pasteur trained first as a crystallographer and chemist, but was soon attracted to the study of biology. He became especially interested in bacteria, as those tiny germs in the air came to be called. His interest was first aroused when a man named Pouchet carried out one of those experiments with food which failed.

Pouchet filled a flask with boiling water, sealed it very carefully, and then, turning it upside down, pushed the neck under mercury. He then took out the cork. Next he made some oxygen from chemicals and passed it straight into the bottle so that some of the boiled water was pushed out. Finally, with a pair of tongs, which he heated strongly to kill any germs it might have on it, he pushed into the bottle a little hay which had also been 'sterilised' by heating strongly. He then corked the bottle again and put it aside. It now contained (*a*) pure oxygen from chemicals, (*b*) boiled water, and (*c*) sterilised hay. It could not possibly contain any bacteria or germs,

said Pouchet. Nevertheless, in a few days the water had become cloudy, and when examined under the microscope was found to be swarming with bacteria. Thereupon Pouchet proclaimed that the prevailing idea that life, even of bacteria, must come from life (in other words, that germs must have parents!) was wrong. Here, these germs had originated quite spontaneously.

Pasteur was quite sure that Pouchet was wrong, and that, in spite of all his precaution, somehow or other some germs had got into the bottle. He repeated the experiment himself very carefully and found out what had happened. Then, in front of a large audience at the Sorbonne, the famous University at Paris, he did the experiment once again. This time, however, he had the room darkened, and had directed on to his apparatus a very brilliant beam of light. Then it could be seen that the surface of the mercury, although it had looked clean, was really covered with a layer of dust. Pasteur showed that when a body was plunged under the mercury, some of these dust particles were carried with it. So that, when the hay was introduced into the bottle, some dust got in too, and with the dust some bacteria.

That was the start of Pasteur's work. He then went on to show that bacteria are floating everywhere in the dust of the air. Catching some dust in gun-cotton, he dissolved the latter away in ether, and examined the residue under the microscope, finding always bacteria. He also showed that in some places air contains far more bacteria than others. For example, in a stuffy bedroom he found very many germs, while in pure mountain air hardly any at all. The experiment by which he showed this is too long to describe here. That is an important feature of Pasteur's work. All his experiments took a

long time and needed a great deal of care and patience. There was nothing quick and spectacular about them.

Pasteur became famous chiefly because he used his knowledge and talent in ways which were of lasting benefit to other people. Soon after he began studying bacteria, he met a man who made alcohol from beetroots. This business was being ruined because the alcohol would not keep but went bad. Alcohol can be made from a number of things, but it is always made from something which contains sugar, such as fruit, barley, or beetroot. The process is known as fermentation and the liquid becomes frothy in the process. Until Pasteur got to work on the matter no one understood how it happened. They were quite content so long as it did happen.

The first thing that Pasteur showed was that, whenever fermentation occurs, living bacteria are always present. When beer is made, the yeast which has to be added is the source of the bacteria. Yeast is composed of thousands of little globes, all stuck together, each of which is a tiny plant-germ. With his microscope Pasteur was able to see these bacteria in every case of fermentation.

The second thing he found was that, in the case of the bad alcohol, a rod-shaped yeast was growing instead of the proper round one. As long as even one of these rods was left in the vat the new lot would go bad, since the one rod-shaped plant was capable of producing thousands more in a very short time. The only thing to do was to scrap the vats and start afresh.

Pasteur realised that the souring of milk and the growing of the mould on cheese were the same sort of change, and so he set to work to look for the plant or creature (for bacteria can be animals or plants) which caused the change. In each case he found it.

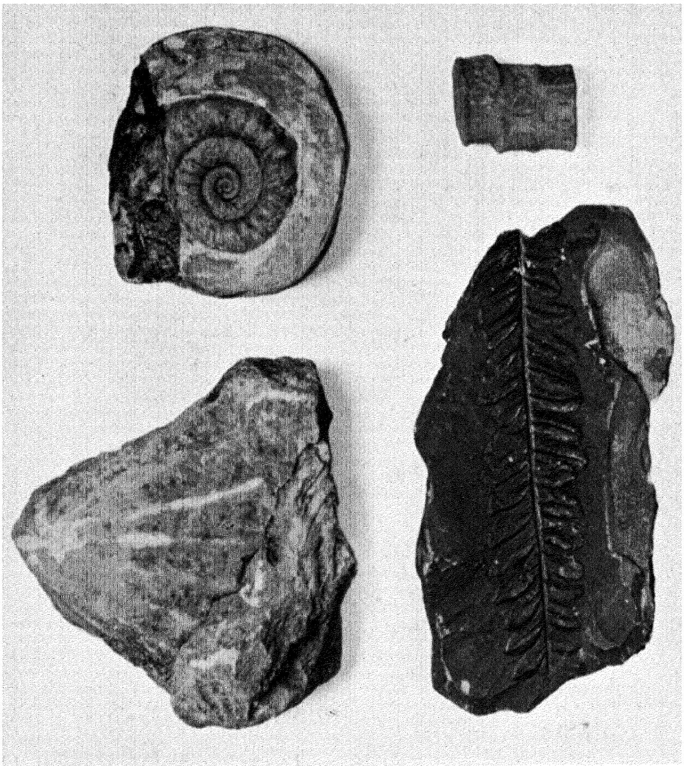
The next piece of work he did was with silkworms. A large part of the south of France depends for its livelihood on the rearing of silkworms and the manufacture of silk articles. It was a dreadful thing, therefore, when, in 1865, a disease broke out amongst the silkworms and they all began to die. Still worse, the new eggs hatched out the next year produced silkworms with the same disease.

Pasteur spent a long time trying to find out what caused the disease and how it could be stopped. He found, as he expected, that it was due to a 'germ,' and he showed the farmers how to recognise which worms carried the germ and warned them against using eggs from those worms. He also told them not to let healthy worms touch any leaves which had had the sick ones on them in case any germs should be left there.

Robert Koch.—Before going on to the most famous of all Pasteur's discoveries we must stop for a moment to hear about another man who was living at the same time and working along the same lines as Pasteur. This man was a German named Robert Koch. He is famous for his discovery that all infectious diseases are due to germs or microbes which can be passed from one person to another. Before he died he had identified the germs producing quite a number of serious diseases, notably, perhaps, those of tuberculosis and of cholera. At the time about which we are talking, however, it was a disease called anthrax, attacking sheep and cows, in which he was interested. This disease seemed to be infectious, but people were not quite sure, as sometimes it seemed to come from nowhere.

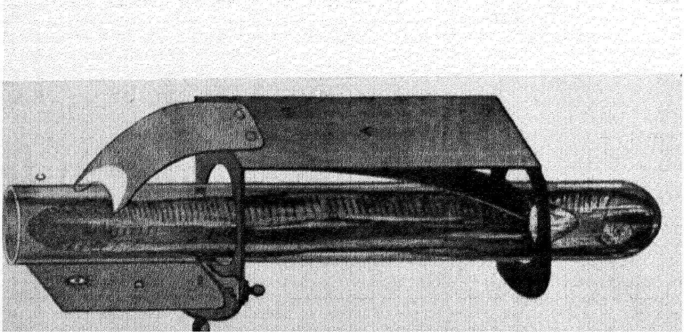
Koch found that mice could be made to take this disease, and so with these in his laboratory he set to

PLATE XX



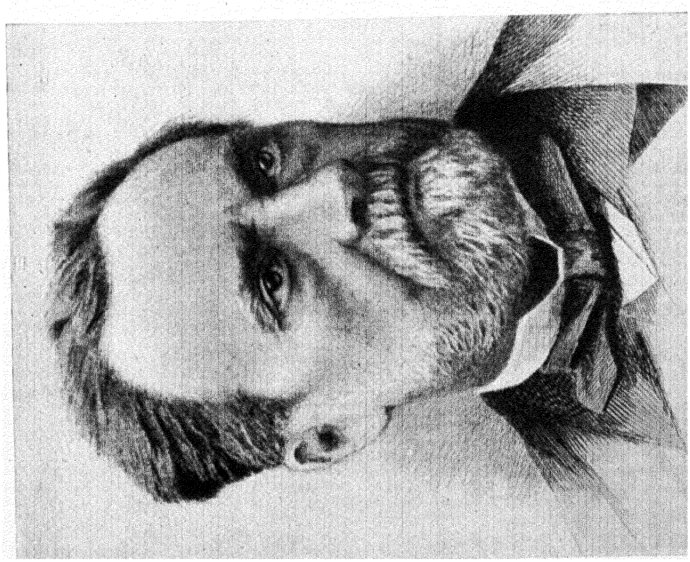
Some Fossils

Top: Fossil fan-shaped shell and a fossil ammonite
Bottom: Fossil leaf and a piece of fossil back-bone



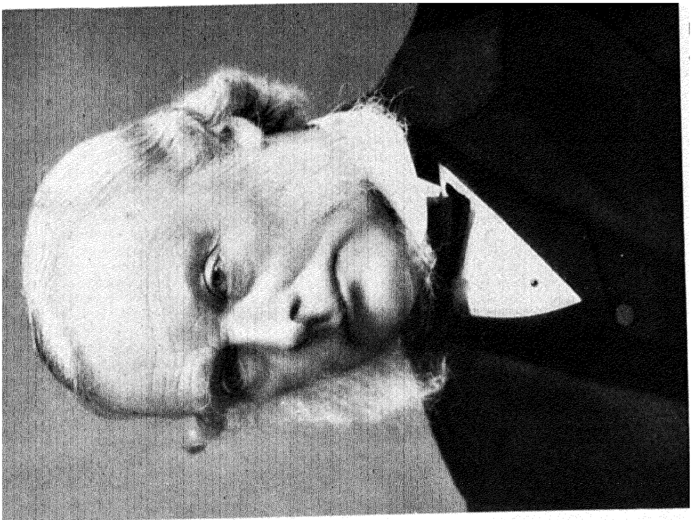
One of Leeuwenhoek's
Microscopes for using
with a Test tube

PLATE XXI



Elliott & Fry

Louis Pasteur



Elliott & Fry

Lord Lister

work to study it. One of the first things he did was to look at their blood under the microscope. He found that the blood of those mice which had anthrax contained lots of little dark rods which made the blood look almost black. As the animal got worse the rods began to grow and stretch, forming a tangled mass of threads. He then injected some of this blood into an animal that had not got the disease and found that it soon developed all the symptoms. So he showed that these rods were the germs which carried the disease.

Pasteur heard of this work of Koch and was very much interested in it. He then wondered whether a germ could not be found which would kill the anthrax germs and so cure the disease. So he also began experimenting with mice. Then a chance arose of experimenting with some cows which had the disease.

There was another man who claimed to be able to cure the disease by rubbing the cow violently, cutting great gashes in her, and then smearing on some horrible ointment. It was a case of the cure being worse than the disease! Pasteur thought that if the cows got better after that treatment they probably would have done so anyhow. However, together they tried an experiment.

Anthrax germs from a sick cow were injected into four healthy cows. Each one soon developed the disease. Then this other man, Louvrier, was allowed to treat two of them in his own fashion, and the other two were left alone. One of the cows which Louvrier treated died and one got better. One of the cows left alone died and the other got better. After that Pasteur was quite sure that Louvrier's treatment was no good.

Pasteur next thought he would see if these two cows which recovered could catch the disease again. He

therefore injected into each of them a large dose of anthrax germs. Nothing whatever happened to them; they remained quite well. So, thought Pasteur, if only the cows could be made slightly ill with anthrax they would afterwards be safe from bad attacks which might kill them. He then went back to his laboratory to try to find out how he could manage to bring this about.

Eventually he found that if the anthrax germs are kept for some time in a bottle they become much weaker and do not have nearly such a bad effect when injected into animals. He therefore proposed that these weak germs should be injected into all healthy cattle so that in future farmers would be safe from this terrible plague which killed so many of their animals. But, of course, there were lots of people who said that it was a very dangerous thing to do and wanted to stop Pasteur. Finally, a great public trial was arranged.

About fifty animals were bought for the purpose and divided into lots. Into one lot Pasteur injected his weak germs or 'vaccines.' Then a little later he injected into all of them strong and virulent anthrax germs. After three days all the animals were publicly inspected. Not one of all the animals which had been injected with the weak germs first was the least bit ill. Of the others almost all were dead and the rest dying. There could be absolutely no doubt that Pasteur was right, and his fame was assured.

Jenner (1749–1823).—Pasteur's idea was not quite new. Nearly a hundred years before an English doctor named Jenner had done something very similar when he first vaccinated people to prevent them getting smallpox. There is a rather similar disease called cow-pox which cows get and often pass on to the people who milk them.

It is, however, very much milder than smallpox itself and people do not die of it. Now Jenner, after years of careful study, came to the conclusion that anyone who had had cow-pox was immune from smallpox—that is, would not catch smallpox however much he came in contact with the disease. Jenner then tried putting some of the pus, or matter, produced in the sores of people suffering from cow-pox into small cuts made on the arm of a boy. Sometime after this he did the same thing with pus from a smallpox sore. In the first case a cow-pox sore was formed; but the pus from the smallpox sore had no effect. So Jenner found a way of protecting people from smallpox. When you are vaccinated you are really given a mild form of cow-pox which will prevent you from catching smallpox if ever you come near to it. Jenner, of course, knew nothing about germs as Pasteur did.

Four years after his famous experiment with cattle Pasteur found out how to prevent the development of hydrophobia, that terrible illness which develops in people bitten by mad dogs. This also was by innoculating them with germs which would overcome those producing the illness.

By this time Pasteur had shown how important the study of bacteria was from the point of view of human welfare. Accordingly there was built in Paris, with money subscribed by people from every part of France, the Pasteur Institute. Here every kind of disease was studied with the object of finding out some scientific way of controlling it. The result is that to-day almost every disease, if taken in time, can be cured. I am sure you will agree that not only France, but the whole world, owes a great debt of gratitude to Louis Pasteur.

Lister (1827–1912).—There is one other man whose name must be classed with those of Pasteur and Koch in this triumphant battle against these tiny but powerful organisms. This man was a Scotsman, Sir Joseph Lister, afterwards Lord Lister. He was a surgeon in Glasgow Infirmary at the time (1860–1870) when Pasteur first began to publish the result of his experiments showing that the air was full of these bacteria, the harbingers of decay and disease.

At that time the surgical wards of a hospital were depressing places. In spite of the skill which surgeons were gaining in performing operations, their patients very rarely got better. This was because the wounds made, instead of healing cleanly and quickly, developed a horrible disease called gangrene, which is a kind of blood-poisoning. The patient became very ill indeed and often died. The same thing happened if it was an accident which had caused the wound; if, for instance, a broken bone pierced through the flesh and skin.

Lister was a very clever surgeon, and it grieved him to feel that all his care and skill were of no avail. After many years of watching and observation he came to the conclusion that there was one kind of wound which never developed this terrible gangrene, and which, if proper care were taken, generally healed quickly without making the patient very ill. This was a wound made inside the body by, say, a broken rib piercing the lung. If, however, in addition, the outside skin were pierced, then such a wound developed gangrene like the others.

When Lister read about Pasteur's work and realised what a lot of seeds of disease were floating in the air, he knew what was the cause of the trouble. The wounds made inside did not come in contact with the air. These

healed, because no germs of disease got to them to make them putrefy. Wherever the air could penetrate, however, there the germs would be also, and disease would follow in their track.

Lister made up his mind that he must cover all the wounds with something which would kill the germs and prevent their working harm. First he soaked dressings in carbolic acid and put them on the wound before he bandaged it. Then he transformed his operating theatre and his wards by banishing everything which would harbour dirt and germs. Above all, he kept them scrupulously clean. Instead of the dirty old garment which surgeons used to wear every time they operated he put on a clean white coat.

In a very short time success crowned his efforts. His patients got well without developing any of the usual bad diseases; while, in the next ward, which was not under his care, the old suffering and misery went on.

It took a long time, nevertheless, to win over the other surgeons to his method. This is known as the antiseptic or 'the against-germ' method. Nowadays it is the aseptic method (*i.e.* without germs) that is used. The disinfectants that kill the germs are also bad for the wounds; so that, instead of killing the germs *on* the wound, care is taken that no germs reach it at all. Everything used in the operation is thoroughly cleansed and disinfected, including the air in the room. As you probably know, all the doctors and nurses wear light washing clothes and the hair is covered up completely. It is essential that everyone should do their job properly. One careless nurse can ruin all the surgeon's work.

III

The Relationship between the Various Forms of Life

So much for the war against germs. Up till now the microscope has shown the way. Now we must go back a little in time and take up the story of another path along which biological knowledge advanced. In this story we shall see how men tried to view all forms of life as a whole; to compare them and link them together, and finally to find out how there came to be such variety among living things.

Linnæus (1707–1778).—The first thing to do in studying a great number of things altogether is to classify them—that is, to arrange together in groups all those which are alike in some chosen respect. Aristotle had done this as far as he was able, but he dealt chiefly with animals. In the eighteenth century a Swedish naturalist, named Karl Linnæus, made a very important classification of all living things. First of all he divided them into two kingdoms, the animal and vegetable. Then he divided each kingdom into a number of 'phyla' according to the broad plan of their anatomy; for example, animals with backbones (vertebrates) and animals without backbones (invertebrates). These Phyla he again divided into classes; classes into orders; orders into families; families into genera; and genera into species. Species is the name he gave to individual kinds of things such as the brown rat, the lion, the tiger, etc.; or the bulbous buttercup, the lesser celandine, the common daisy, etc., among the plants.

Two examples will serve to illustrate this classification. As we have seen, one of the phyla into which the Animal Kingdom is divided is the Vertebrata, comprising all

animals with a backbone. In this *Phylum* is the *Class* Mammalia, which includes all mammals, *i.e.* animals which do not lay eggs but bring forth their young alive and suckle them. The *Order* Carnivora contains all flesh-eating mammals. The Cat-tribe (Felidæ) is a *Family* of this order; and in it we find the *Genus* Felis which comprises the *Species* Felis domesticus (domestic cat), Felis leo (lion), Felis tigris (tiger), and so on.

In the Vegetable Kingdom, the common buttercup (Ranunculus arvensis) is a *Species* of the *Genus* Ranunculus of the *Family* Ranunculaceæ of the *Order* Dicotyledons,[1] of the *Class* Angiosperma,[2] of the *Phylum* Spermatophyta.[3]

Animal Kingdom		*Vegetable Kingdom*
Vertebrata	(phylum)	Spermatophyta
Mammalia	(class)	Angiosperma
Carnivora	(order)	Dictoyledons
Felidæ	(family)	Ranunculaceæ
Felis	(genus)	Ranunculus
Felis domesticus	(species)	Ranunculus arvensis

All this tidying up was very useful; but, as so often happens, people got so interested in giving things their proper label that they lost interest in the things themselves. The Linnæan system of classification is used in much the same form to-day.

Cuvier (1769–1832).—The next man who figures in this story was a Frenchman, Georges Cuvier. He was born in 1769 and died in 1832, so that he lived through

[1] Dicotyledons = Plants bearing two rudimentary leaves in embryo.
[2] Angiosperma = Plants bearing seeds in closed ovaries.
[3] Spermatophyta = Plants bearing seeds.

stirring times. During the Reign of Terror in the French Revolution he was acting as tutor to the sons of a wealthy man and lived for some years on the coast of Normandy, away from all the excitement in Paris. While there he had plenty of time and opportunity to follow his interest in Natural History and became acquainted with several of the leading naturalists of the time. Later he went to Paris to be in charge of the Jardin des Plantes—or Botanical Gardens—and finally became famous as a friend of Napoleon, who gave him a high office of state.

Although, originally, Cuvier's interest lay with plants it was with animals that he did his most valuable work. He studied all the different kinds of animals he possibly could and compared their different parts. For example, he compared the organs with which such different animals as man, a horse, a fish, a spider, an insect, etc., breathed or digested their food. Again he compared the nervous systems of all these animals and so on. He realised that to be able to understand the simple types of animals would be a great help in studying the more elaborate processes in the higher types.

Cuvier divided animals into four classes only:

(1) The vertebrates, or the animals furnished with backbones. These include mammals, birds, reptiles, and fishes.

(2) Molluscs—which include all the shell-fish.

(3) The articulated or jointed animals, such as crabs, lobsters, spiders, and insects.

(4) The radiated type, such as starfish.

Near Paris a rock named Gypsum is to be found from which the famous Plaster of Paris is made. At the beginning of the nineteenth century workmen digging in

these rocks found a great number of bones and fossilised remains of animals, some of them of gigantic size.

Fossils had been found and known for many centuries, but various opinions had been held as to what they really were. A fossil is a bit of rock or stone having the shape or the impression of a part of a plant or an animal. (See Plate XX.) Fossilised ferns can sometimes be quite clearly seen on a piece of coal. The cliffs in many parts of England often contain the fossils of shells; chalk-pits are usually full of them.

All sorts of queer superstitions were at first held about fossils. The first man to realise that they were the remains of animals and plants which had formerly been alive and had become hardened with time was Leonardo da Vinci. By the time of Cuvier this was universally recognised, but there was still a great deal of discussion as to how they got there. The favourite explanation was that they were the remains of animals that had perished in the great flood at the time of Noah.

When all these new fossils were unearthed near Paris, Cuvier at once set to work to examine them. Remember that he had spent years studying the anatomy of every kind of animal, so that he was especially fitted to undertake this work. Many of the bones he identified easily, but a number, he found, did not belong to any animal which was then known, although they were very like those of elephants in some respects. This was interesting, because it showed that there used to be animals on the earth which are no longer to be found there.

His interest once turned in this direction, Cuvier spent the next twenty-five years examining fossils from all parts of the world. Gradually he came to the conclusion that, from time to time, certain types of animals died and new

ones were formed. The older kinds were, of course, always to be found buried deeper in the earth. Now Cuvier was a firm believer in the theory that the animals whose remains were found as fossils had been buried in the earth at the time of a great flood. His new discoveries, however, forced him to the conclusion that there must have been a series of floods—catastrophes he called them. He stuck firmly to this opinion all his life.

Lamarck (1744–1829).—Side by side with Cuvier there was working in Paris another scientist, considerably less honoured and deferred to than Cuvier by his contemporaries, but who is now judged to be by far the greater man of the two. This was Jean Baptiste Lamarck. It was largely through his efforts that Cuvier gained his appointment at the Jardin des Plantes. In later years, however, Cuvier, the favoured of Napoleon, did not treat Lamarck with the kindness and respect which he owed to him.

Lamarck was also interested in the fossils, but, while Cuvier devoted himself mainly to those of the vertebrate or backboned animals, Lamarck studied the invertebrates with great care. His investigations led him to conclusions which differed from those of Cuvier. He found that, although many forms of animal life disappeared and others took their place, there were no definite times at which these disappearances took place. While some forms disappeared, others lived on. There was, in fact, to be found a gradual succession of forms of life.

William Smith.—Meanwhile, an English surveyor was making discoveries which confirmed Lamarck in the conclusion to which he was gradually coming. William Smith was engaged in the work of building canals up and

down the country. This meant, of course, a good deal of digging and excavating. He was of a very observant type of mind, and his attention was soon attracted by certain regularities to be found. The earth through which he cut was arranged in definite strata or layers of rock which always appeared in a definite order. In these strata fossils were often to be found embedded, but—and this was the interesting point—the fossils found were

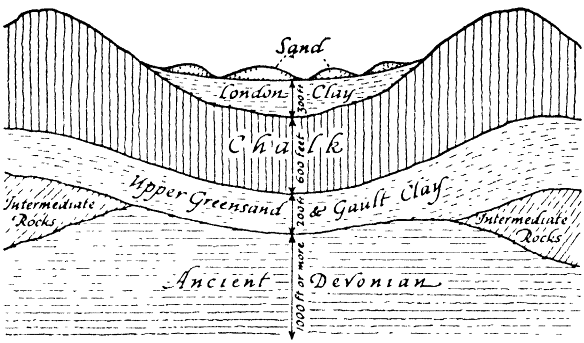


FIG. 40.—Showing the strata beneath London

characteristic of the particular stratum. For example, there was a certain fossil of an extinct snail-like shell animal called the ammonite. There were also three layers of clay in the strata through which he dug; one on top, which is called London clay; one just underneath the chalk, called the gault clay; and one much lower, called the Oxford clay. In the London clay no fossil ammonites have ever been found, but there are a great many fossil fruits of palms and conifers. In the gault clay there are no fossil plant fruits, but ammonites of an irregular spiral shape are to be found. Finally, in the Oxford clay, there are huge numbers of perfectly regular ammonites.

In some places William Smith found that the top layers had been worn away, exposing lower layers, but once he had studied the layers carefully where they came in the right order he was always able to recognise any particular layer by the fossils which it contained.

All this strengthened Lamarck in his belief that there had not been a series of sudden changes in the forms of life inhabiting the earth brought about by sudden cataclysms such as floods. Instead, he felt sure that the changes had been slow and gradual and that one species had 'evolved' from another. This theory of simpler animals gradually changing and giving rise to more elaborate species in the course of long periods of time is known as the Theory of Evolution. It was not quite a new idea. Certain Greeks had thought of it. There are not very many ideas which the Greeks did not think of first, but here again the new thing was the evidence on which the theory was based.

Lamarck probably did not think of all the various forms of life as starting from one very simple form, such as the protozoa, as we do now. He thought that the changes just took place within certain groups. His explanation of how the change took place was a very ingenious one. For example, he said, suppose a certain antelope found he could reach up and eat the leaves of trees. Liking this food he would continue to stretch up, with the result that his neck would grow gradually a little longer. The young of this antelope would be born with necks rather longer than usual, and would stretch them still more by eating leaves off trees. Their young would have still longer necks, and so on, until finally we come to the giraffes of to-day. Do you see the idea? Lamarck thought of a good many other examples of the way

animals might alter themselves by constant use of a certain part. We shall come back to this explanation of Lamarck's later. In the meantime we shall see how the evidence for the *fact* of evolution gradually accumulated. You must realise that knowing for certain that a thing has happened is by no means the same as knowing *how* it happened. There has been a good deal of confusion over this in the case of evolution, and people who do not know much about it are inclined to think that because we are not yet certain as to *how* evolution occurred we do not know for certain that it has occurred. This is quite wrong. We cannot possibly go further into it here, but there is no doubt at all that man and all the higher animals have evolved from the very simplest forms of life. The change has been very gradual, but we now know just what forms of life were present on the earth at any particular time, and also how long it took for these changes to occur.

Charles Lyell (1797–1875).—The man who was responsible for a great deal of our knowledge about the age of the earth and the story of life upon it was Charles Lyell, a very famous British geologist. Geology is a branch of science which we have not, so far, mentioned. It concerns the study of the earth itself. Lyell realised that the changes which have taken place in the earth in the past can only be understood by studying the changes which are going on at the present time. These are the changes to which he paid special attention:

(1) Rivers are continually cutting channels through rocks. In so doing they bring down the material worn away as sediment which is deposited at their mouths, often forming deltas.

(2) Rocks are also worn down by frost, wind, and

wave, and the fine sand so formed is distributed by wind.

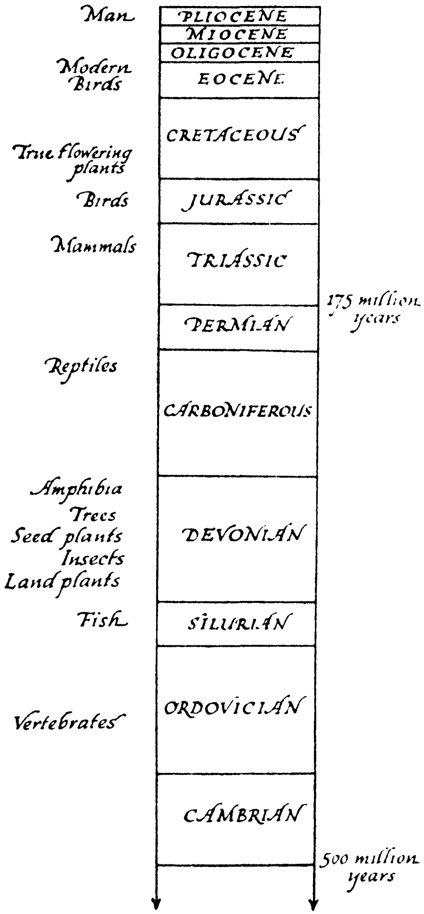


FIG. 41.—Diagram to show the development of forms of life during the last 500 million years. More primitive forms existed for very many millions of years before this

(3) Animals die and are covered up by the material distributed, as shown above.

In this way successive layers are built up in which dead animals become embedded. The soft parts decay, and the harder shell is filled up by sediment. As the thickness of the layer above increases, the pressure hardens the underneath layers, so that the fossils are formed.

Lyell calculated the rate at which the layers were being formed at the present time, and so was able to determine, from its thickness, the period of time occupied in forming some definite stratum. In this way he was able to fix definite periods of time during which certain forms of life existed on earth. The diagram will give you some idea of what has

happened in past ages. No doubt many questions will occur to you, but you must go to a book on Geology for your answer.

Charles Darwin (1809–1882).—The name which is always connected with the Theory of Evolution is that of Charles Darwin. This is because he devoted many years of study to the subject, and finally wrote a book in which the evidence put forward was so conclusive that a very large number of people were convinced. Darwin did not claim the idea to be new. What was new was his explanation as to how evolution occurred.

First let us see how Darwin came to study the subject at all. As a boy he lived in a village near Shrewsbury, where his father was a doctor. He and his brother were true country boys, and took a lively interest in all the country life about them. Charles went to Cambridge as a young man, but could not decide what he wanted to do after that. Then he heard of a ship called the *Beagle*, which was to go off on a five-years' voyage to southern seas to make new charts. The captain of the ship thought that there ought to be a naturalist on board who would be able to examine and write about all the animal and plant life in the seas and lands which they visited. The Government did not agree with him, and would not pay for one, but said that, if he could find any one who would go for nothing, it had no objection.

Darwin thought what a splendid thing it would be to go with the *Beagle* as its naturalist. He had learnt a lot of natural history at Cambridge, and knew about the new ideas concerning the earth and the possibility of evolution. His father did not want him to go; but his uncle, Josiah Wedgewood, backed him up, and in the end he went.

It was a wonderful experience. They went down the east coast of America, up the Amazon and back, round Cape Horn and up the Pacific coast. Finally they crossed the Pacific and came back home by Australia and New Zealand. Altogether, they were away five years.

During the whole time Darwin examined and, whenever possible, collected specimens of every conceivable kind of plant and creature, and a great number of fossils. When he got home it took him years and years to go through all his specimens. He wrote an account of his voyage in a very interesting book called *A Naturalist's Voyage in H.M.S. Beagle.*

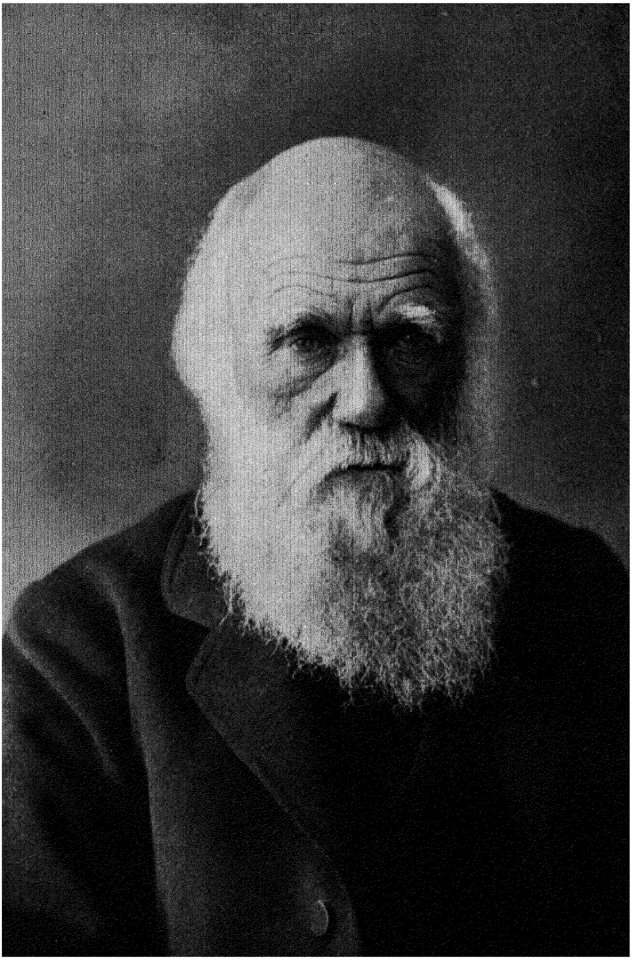
There is not space here to go into all the evidence that Darwin collected. The chief point was that it was quite impossible to fix on a definite number of distinct species. One kind gradually merged into another by infinitesimal steps. Darwin, at the end of twenty years, published all the evidence in his famous book *The Origin of Species.* In this he also gave his explanation of how evolution had come about. It was not the same as that of Lamarck.

He first of all pointed out that of all the tremendous number of young creatures born only a very small proportion survive. This is most strikingly true among the lower forms of life.

He then suggested, what is also undoubtedly true, that the ones that do survive are the ones that are most fitted to cope with the surrounding circumstances. In other words, the weakest go to the wall. This theory he called that of the 'Survival of the Fittest.'

In any given species the individual members are not all identical. For example, some animals can run away from their enemies faster than others of the same kind.

PLATE XXII



Charles Darwin

Elliott & Fry

Those that can run fastest will live; the others will be killed.

Then, Darwin said, the young of fast-running survivors will tend, on the whole, to run a little faster than the average of the preceding generation. In this way the species gradually changes by natural selection of the fittest, and becomes faster moving. Probably the ability to run fast was due to some slight difference in the formation of the legs or feet, and the new species produced would all tend to have this character. If they had not, they probably would not be able to run so fast, and so would be killed.

At the present time scientists find it rather hard to make either Lamarck's or Darwin's explanation fit the facts completely; and they have not yet agreed upon the true explanation as to how evolution occurred. They all agree, however, that it has occurred.

Lamarck's explanation as to how evolution occurs is usually known as the 'Inheritance of Acquired Characteristics.' An individual is supposed to alter some part by use, and this 'acquired characteristic' is then inherited by the offspring. Darwin's explanation is known as 'Natural Selection by the Survival of the Fittest.' Scientists to-day cannot agree as to whether these 'acquired characteristics' can be inherited by the offspring of parents who acquire them. The evidence is chiefly against it. On the other hand, the small differences which Darwin suggested are inherited and bring about evolution, are now generally considered to be too small to bring about a change in the time actually taken. Until more is learnt about inheritance, the question must remain unsettled, for it is on this point that scientists do not agree.

IV

Heredity

It is only quite recently that anything has been known certainly about how inheritance functions. You have only to look at a family to see, quite definitely, that certain characteristics of the parents are inherited by the children. Yet the children often have other characteristics possessed by neither of the parents.

By the nineteenth century it was known that in the higher animals and plants a new living organism was always produced in a definite way. In all species there were two kinds—the male and the female. These produced certain characteristic cells differing from all the other cells of which the organism was composed. These were called *gametes*. In a flowering plant the male gametes are the pollen grains, and the female gametes are the ovules. In both plants and animals the male gamete is small and easily detached from the parent; but the female gamete remains attached to it. To produce a new organism, a male gamete has to reach a female gamete and join with it. From the cell formed by the fusion of these two gametes the new organism grows.

The difficult question for scientists to decide was as to how all the characteristics of the parent could be passed on to the offspring by means of the one small cell. Darwin supposed that minute particles from all parts of the body collected in the gamete so that all parts made their contribution. This was only an idea. He had no proof.

Gregor Mendel (1822–1889).—During Darwin's lifetime an Austrian monk, Gregor Mendel, was carrying out some very important experiments with ordinary garden

peas, which he grew in the monastery garden. When he published these results no one took any notice of them and he was very much disappointed. In 1900, however, somebody came across his papers, and realised how very important they were, so that now the name of Mendel is very famous.

The merit in Mendel's work lies in the fact that, in examining inherited characteristics, he only bothered about one definite character at a time. For example, he worked with two kinds of garden peas, a tall kind about 6 feet high, and a short kind only about 1 foot.

First of all he made sure that if pollen from a tall plant was made to 'fertilise,' that is, join with an ovule of another tall plant, all the seeds produced grew into tall plants without exception. Similarly, a short plant fertilised by another short plant always gave short plants.

Then he took pollen from a tall pea and fertilised the ovules of a short pea, tying the flower of the latter up in muslin so that no pollen except what he put there himself could reach it. He also took pollen from a short pea and fertilised a tall one.

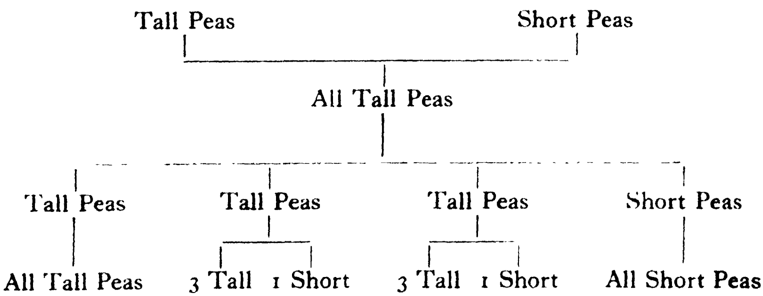
He then planted out the seeds produced in these two ways. They all grew into tall peas as tall as the tall parents, not half as tall, as might be expected. *The shortness of the one parent had apparently disappeared altogether.*

Next he fertilised each of these second generation tall plants with their *own* pollen. This is called self-fertilising. The resulting third generation of peas was most interesting. A quarter of the resulting plants were *short* and three-quarters were *tall. The character of shortness had not been lost after all, only hidden.*

In the fourth generation, produced again by self-

fertilisation, he found that all offspring of the short third generation peas were short and no tall peas were obtained from these so long as they were self-fertilised. Of the tall plants of the third generation, one-third of them produced tall plants only. The remaining two-thirds produced three tall and one short out of every four, just like the second generation.

We will put these results into a diagram:



Now let us see how Mendel explained this. He said nearly all inherited characters go in pairs, such as tallness and shortness, whiteness or colour, smoothness or wrinkles, and so on. Those are characters of peas, but he thought pairs could be found for nearly everything.

Each gamete produced by the parent carried something which gives rise to one of these characters. But each gamete could only carry *one* of these alternative pairs, never both. This means that, since the original tall peas always produced in all succeeding generations tall peas when self-fertilised, then every gamete carried the character of tallness. Similarly, all the gametes of the short peas carried the factor of shortness.

Now, when the gametes of these two kinds of peas joined together, the new cell produced in each case (called the Zygote) must contain *both* characters. Why then

were the plants produced only tall ones? Mendel supposed that the character of tallness must be stronger in effect than that of shortness. He said it was the *dominant* character, while shortness was a *recessive* character. Mendel did not know what it was in the gamete which gave rise to the characteristic, so he called the something 'a factor.' The second generation plants contained both the factor for tallness and that for shortness, but, because the factor for tallness was dominant, they were all tall.

When this second generation of peas produced gametes, each gamete could only carry *one* of the factors, so that, of all the gametes produced by any one plant, half would carry the factor for tallness and half for shortness. Now, when these gametes join together by self-fertilisation to produce new zygotes there are three possibilities:

1. Two 'tall' gametes may join together.
2. Two 'short' gametes may join together.
3. A 'tall' and a 'short' may join.

In the first case the new plants must be tall; in the second they must be short; while in the third they will be tall because, although the 'short' factor is present, the tall dominates it.

A diagram will make this quite clear (Fig. 42, p. 262). Out of every four plants in the third generation, therefore, there ought to be three tall and one short, which is what Mendel found.

During this century a great deal more work has been done on the inheritance of certain characteristics and Mendel's ideas have had to be altered a little to meet new facts. Nevertheless, the debt owed to him is very great, for he laid the foundation of all the work of this kind.

This work is not only important from a purely scientific point of view, but from a much wider social one. What are now known as 'Mendelian' characters have been worked out for the human race in many cases, and it has been found that many bad characteristics, such as certain physical defects, are 'recessive' characters like the shortness in peas. This means that they can be hidden in one

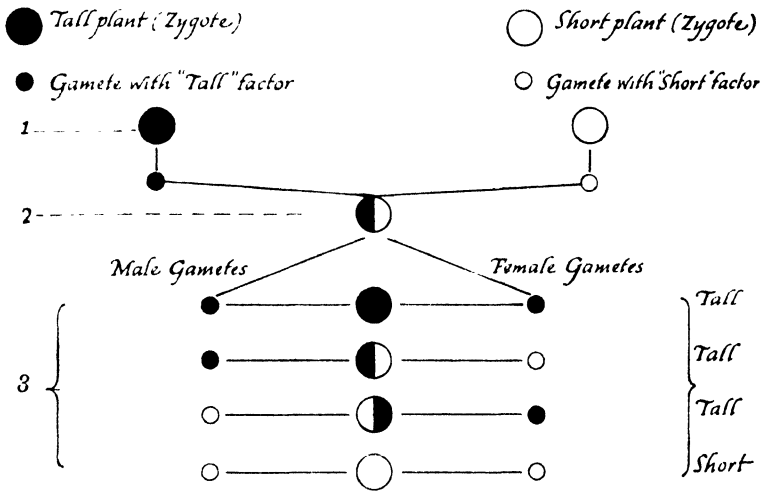


FIG. 42

generation but crop up in the next if they happen to be hidden in *both* parents.

It would obviously be a good thing if bad characteristics which weaken the human race could be cut out, but the whole matter is, of course, extremely complicated. The biologists of the day are hard at work on these and other problems concerning the health of the community.

CHAPTER XVI

The Modern Road

In Part I of this book we followed the early road-makers as they blazed out the first trails which gradually widened and straightened till, by the work of Galileo and Newton, the great highway of Science was built on firm foundations. In Part II we have seen how the highway was divided into separate tracks each carrying its own traffic. What of the road which is still being made?

Three regions are occupying the attention of our greatest scientists to-day. These are:

(1) the realm of the extremely small, which is to be found inside the atom;

(2) the realm of the immensely large, of the great universe about us;

(3) and finally, that mysterious complex world of Life itself.

The work to be done on the road into each of these regions is still pioneer work. The country has to be prospected as the road is built, and the ingenuity of the road-builder is often taxed to the utmost to overcome the obstacles in the way.

Quite a fair stretch of each road, however, has already been made, and the workers on the road are becoming familiar with the country. For us, however, it is not quite so easy to follow them, and we must be content here with a very brief account of some of their most important discoveries.

First, let us explore, with them, the inside of the atom.

During the greater part of the nineteenth century, Dalton's picture of hard unbreakable atoms, like billiard-balls, had been kept by all chemists and had served their purpose very well. Since the end of the century, however, one discovery after another has shown that this picture was by no means a true one. I am not going to try to tell you how these discoveries were made, but shall just give you a general idea of what sort of a picture we hold to-day of the inside of an atom.

To begin with, an atom is very far from being solid, like a billiard-ball. The greater part of an atom, like the greater part of the universe, is empty space. Secondly, apart from this empty space, the atom is made up chiefly of electric charges.

In the very centre of the atom is the part of it which gives it its weight, called the nucleus. This nucleus bears a positive charge of electricity. Circling round the outside of the nucleus, in much the same way as the planets circle round the sun, are a number of negative charges of electricity. These negative charges are called *electrons*; while the weighty positive charges making up the nucleus are called *protons*. Since an ordinary atom is neutral—that is, it is not 'electrified'—the charge carried by the electrons outside must always equal the charge on the nucleus.

In the solar system the general rule is that only one planet follows the same path round the sun. In the atom, on the other hand, we may find as many as thirty-two electrons in a ring. The outside ring, however, has never more than eight. The lightest atom known is the Hydrogen atom. This has one positive charge on its nucleus and one electron circling round it. Helium, the next lightest

substance, has two electrons outside, both following the same path. Next in order of weight comes a rather rare metal called Lithium, which has three electrons outside the nucleus of its atom, two revolving on an inner ring and one on an outer. Taking the elements in the order of their atomic weight, each of the next seven atoms adds an electron to the outer ring until there are eight altogether. Then another ring is started; and so on.

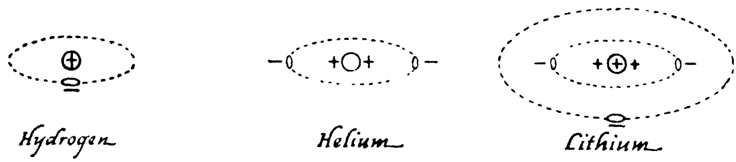


FIG. 43.—Atoms of various elements

As you know, negative and positive charges attract each other; while charges of the same kind repel each other. The inside of an atom is, therefore, full of these forces, but as a rule the charges are so arranged that the forces in different directions just balance each other, and the atom —like the solar system—is stable. As the charges pile up, however, a point is at last reached where the strain becomes too great and some of the atoms break down under it. The atom of lead has eighty-two electrons circling round, and a positive charge of eighty-two on the nucleus; and Bismuth, another metal, has eighty-three electrons. These are the two heaviest atoms which are stable. There are several elements known which have heavier atoms, but in every case we find the strain on the nucleus has reached its limit. If we take a lump of any one of these elements we know that, in a fair proportion of the atoms making up the lump, the nucleus is exploding and throwing out bits of itself, only settling down quietly

when it has reached the size of the nucleus of the atom of lead.

The substances with disrupting nuclei are known as *radio-active* substances. The best known of them all is Radium, which was discovered by M. and Mme Curie in 1898. It was mixed with the first radio-active substance to be discovered, Uranium. The story of the discovery of Radium is a famous one, and the reason for its fame is twofold. First, Mme Curie was almost the only woman to win a place of first rank amongst the discoverers in pure Science. Her husband was killed in a street accident ten years after the discovery, but Mme Curie lived on until 1934, and devoted her life to scientific work. Secondly, the result of their labours, the element Radium, has proved to be of great service to man in the hands of doctors for the alleviation of human suffering.

The investigation of radio-active substances showed that the disrupting atoms were shooting out three different kinds of rays, known as the Alpha, Beta, and Gamma rays. The Alpha rays consist of very swiftly moving particles carrying a positive charge. Actually these Alpha particles consist of four protons (positively charged particles) in a lump. The Beta rays consist of a stream of electrons which have been embodied in the nucleus. Finally, the Gamma rays have been found not to consist of particles at all, but to be very rapid vibrations of the ether, or waves of very short wave-length. They are, in fact, very short, or 'hard' X-rays, but are more usually known as Becquerel rays, after the man who discovered them.

These are the rays which are used in our hospitals to try to cure the dreaded disease of cancer by killing the growth which causes it. The rays, however, are not discriminating in the tissues which they destroy, and

so have to be used with the greatest caution. The best thing which will really shut them off, by absorbing them, is a thickness of several inches of lead. They pass through other materials just as light passes through glass. Accordingly Radium is always kept shielded by lead. The actual dose to be used is in a lead 'needle,' and a bunch of these needles is kept surrounded by blocks of lead several inches thick, locked up in a safe. Every one working with Radium wears rubber gloves, and, throughout, the greatest care is exercised. Nowadays bad burns only come from carelessness in its use; but the early workers, not understanding the substance with which they had to deal, suffered badly.

It was the discovery of what was happening to the atoms of radio-active substances which first gave scientists any knowledge of what the inside of the nucleus was like. As we have said, Becquerel was the name of the man who first investigated a radio-active element, and the substance which he investigated was Uranium, the heaviest element of all. Then M. and Mme Curie discovered, mixed with Uranium, the far more active element Radium. This, as a matter of fact, is formed from Uranium after it has shot off some of its nucleus, as alpha and beta rays. Radium itself is, of course, not stable, and its atoms also begin to break up, although any *one* atom may remain a Radium atom for as long as a thousand years. In a lump of Radium, however, there are always some atoms breaking up and shooting out rays.

The investigation of the rays and the transformations of Uranium and Radium as they break up was carried out chiefly by Professor Soddy and his helpers at Oxford. Electrons had previously been discovered in quite

another way by Professor J. J. Thomson at Cambridge. Here there is a very famous laboratory known as the Cavendish Laboratory. The money for this laboratory was given by one of the descendants of the family to which the great scientist Cavendish belonged, and is one of the greatest 'research' laboratories in the world. The chief purpose of the workers in the Cavendish laboratory during the last thirty or forty years has been to find out all they can about the inside of the atom. The leader in the work has been Dr Ernest Rutherford, who has now been made Lord Rutherford in recognition of his achievements.

The picture I have given you of the inside of an atom was made by Lord Rutherford. As a matter of fact, although it fits chemical ideas and facts very well indeed, workers in Physics are not quite so pleased with it and are looking for a slightly different one. This picture, however, is the easiest one for us to understand, and so long as we do not think we know the last word on the matter it will serve us very well until the scientists can give us another one which they are surer about.

Let us now consider what is the modern explanation of what happens when things become electrified. Such a state is most easily produced, you will remember, by rubbing two things, such as wool and sealing-wax, together. The sealing-wax then acquires a negative charge and the wool an equal positive charge. To begin with, all the atoms composing both wool and sealing-wax are quite whole; that is to say, they have their full number of electrons revolving round a positively charged nucleus. In the rubbing, however, some of the outer electrons of the atoms composing the wool get rubbed off on to the surface of the sealing-wax which, therefore,

quite obviously has then a negative charge. Since some of the atoms in the wool have lost electrons, the nuclei of these atoms will have a greater positive charge than the negative electrons left. The wool, as a whole, will therefore be positively charged.

The important thing to remember about these new ideas is, that only the *electrons* or negative charges can move about from one part of a body to another. The positive charges are firmly locked up in the centres of the atoms. If, however, electrons leave one part of a body, that part of the body will become positively charged. All we have learnt about positive and negative charges still holds so long as we remember that when we say a positive charge moves in a certain direction, what is really happening is that a negative charge (or a stream of electrons) is moving in the opposite direction.

Since the electrons are on the outside of the atom, it proved a comparatively easy matter to knock them off and find out how they are arranged. It was much harder to get at the nucleus. Quite recently, however, Lord Rutherford and his helpers have succeeded here. They have done this by shooting at the nucleus! In Rutherford's first experiment the missiles were those very swiftly moving alpha rays, which, by the way, are really atoms of helium without their attendant electrons. A stream of these rays was sent into the gas nitrogen and a kind of photograph taken of what happened. Just one or two of these particles happened to hit the nucleus of one of the nitrogen atoms. Experiments of the same sort using other gases and other bombarding particles have been carried out, and quite literally bits have been knocked off the nucleus in some cases. The nucleus left would, of course, be different, and so really what

they have done is to change one kind of atom into another! A short time ago Lord Rutherford gave a lecture which he entitled 'The Transmutation of Matter.' After all, modern scientists are doing what the old alchemists tried to do, though with somewhat different aims!

In the section on Astronomy we travelled some way along the modern road which explores the universe and there is not a great deal to add. One thing follows directly on what we have just learnt about the inside of an atom. The interiors of the hot stars and of the sun are very, very dense, although they are not solid. They are not solid because the molecules are vibrating far too quickly to exist in the solid state. Because they are so dense, however, there is not room for all the electrons in their proper circles with all the space between. These have got squeezed out, and the nuclei of the atoms are all very near together. This at any rate is what our modern scientists think. Sir Arthur Eddington, one of Britain's foremost astronomers, has written a fascinating book called *Stars and Atoms*, which is very well worth reading, and gives a splendid picture of the Universe as it is known by astronomers to-day.

The name of Einstein is one which is very often on the lips of the scientific leaders of to-day. Why is this? It is because Einstein has proved himself to be one of the giants among scientific men. Formerly Newton has been almost universally acclaimed as foremost among these giants. Now, undoubtedly, Einstein takes a place at his side.

To explain to you what Einstein has done is, I fear, a hopeless task. Even among people who have had some special scientific training there are comparatively few

who can follow him easily. His is a mathematical achievement, and except to mathematicians the way after him is barred. We can, nevertheless, perhaps get some small idea of what the results of his work mean.

To begin with, he showed that Newton's laws of motion and of gravitation (which we explained fairly fully in the first part of this book) did not explain everything as completely as was thought. In ordinary everyday life on this earth Newton's laws hold very well, and machines and experiments planned with them as a basis all work perfectly well. But in the much vaster world of the universe, or in the tiny world inside the atom, these laws break down. Einstein, however, has supplied us with others; or rather, so corrected Newton's laws, that they hold, so far at any rate, in all three worlds.

We hear curious statements about Einstein's discoveries and a good deal about the 'fourth dimension,' which is Time. He certainly has shown that we keep space and time too separate in our minds and that really they are only part or dimensions of the one 'Space-Time' of which the universe is composed. We have got so used to thinking of volume as the limit following length and area, that to go one further and multiply by time to get Space-Time makes our brains reel! Luckily modern mathematicians have very agile brains, and are able to move, quite at home, in this new country.

One interesting thing Einstein has told us about our universe of Space-Time is that it is not infinite, stretching on endlessly, but is quite definitely limited. The correct expression is that it is 'finite.' If you could set out on a journey through the universe—apparently in a straight line—you would eventually come back to your starting-

point. In fact the universe is, in four dimensions, what the sphere is in three and the circle in two.

Strangest of all, Einstein now tells us that all matter is just a crinkle or a lump in this Space-Time universe. Stars, such as our sun, are big crinkles, planets smaller ones, and so on; the bigger the mass the bigger the crinkle. But it is all very difficult and seems rather far away from the roads we travel every day.

In the third realm, the realm of Life, the road seems rather nearer to us. In fact, it is all-important that it shall eventually be the everyday road along which mankind travels. For undoubtedly this, of all the roads which science has carved out, seems to be the one which is going to lead to the goal towards which men, since they first appeared on earth, have been struggling. They have not known, and still do not know, quite what that goal is.

One fact has recently emerged as the result of modern research, which is that a knowledge of the biological laws governing human life is all-important in the efforts which are made to ameliorate social conditions. Otherwise it may happen that an apparent improvement in the conditions of life of one generation may only make matters worse for the next.

In the section on Biology I have indicated the lines along which modern biologists are working. Three are especially important. The first is the study of heredity, by which we hope to be able to understand and control what we, in this generation, pass on to those who follow.

Secondly comes the study of the working of the human body, and the influence on it of the food we eat and the

conditions in which we live. The importance of this work is obvious.

Finally, there is the study of the working of the human mind. This undoubtedly will prove a very important bit of the road. But it requires very special training, and the making of this road will be very slow.

SUMMARIES OF PART II

SUMMARY TO CHAPTER X

I

The Hon. Robert Boyle (1627–1692)

'The Founder of Modern Chemistry.' Author of *The Sceptical Chymist*. He defined the term 'Element.' He urged that the first object of all chemists should be to search for the elements.

The Phlogiston Theory

All inflammable substances contain Phlogiston. When these substances burn, phlogiston escapes. No inflammable substance can, therefore, be an element, except pure phlogiston.

Dr Joseph Black (1728–1799)

He carried out the *quantitative* investigation of chalk, magnesia alba, and the mild alkalis. He discovered that each of these contained a gas which he called 'Fixed Air,' now known as Carbon Dioxide.

Chalk = Quick-lime + Fixed Air.
Mild Alkali = Caustic Alkali + Fixed Air.

The Hon. Henry Cavendish (1731–1810)

(*a*) He realised the importance of measurement in Science. By weighing equal volumes of the gases, he showed that 'inflammable air' (hydrogen) and 'fixed air' (carbon dioxide) were totally different from each other and from common air.

(*b*) He showed that water was not an element but a compound of inflammable air (hydrogen) and dephlogisticated air (oxygen).

Dr Joseph Priestley (1733–1804)

(*a*) He invented the pneumatic trough for collecting gases or 'airs' which he obtained by heating various substances.

(*b*) His most famous discovery was that of oxygen which he called Dephlogisticated Air. He obtained this by heating Red Mercury Calx.

(*c*) He also collected and described Ammonia, Hydrogen Chloride, and the Oxides of Nitrogen.

II

Jean Antoine Lavoisier (1743–1794)

(*a*) He overthrew the Phlogiston Theory and gave in its stead the modern theory of Combustion.
By experiment he showed that air consists of two parts; an active part, oxygen, and an inactive part, nitrogen (or azote).
When any substance burns in air, it combines with the oxygen. The calx produced is, therefore, never an element, while the inflammable substance may be.

(*b*) He drew up a list of substances which he considered to be elements.

(*c*) He introduced a systematic scheme of names for chemical substances which is still in use.

Karl Wilhelm Scheele (1742–1786)

(*a*) He discovered oxygen independently of Priestley, and two years earlier

(*b*) He discovered Chlorine.

(*c*) He isolated a number of 'vegetable' acids.

Sir Humphry Davy (1778–1829)

(*a*) He invented the safety lamp to prevent explosions in mines from the naked candle-flame.

(*b*) He established the fact that Chlorine was an element. Since the well-known acid, hydrochloric acid, contains only hydrogen and chlorine, he thus showed Lavoisier to be mistaken in his 'oxygen-theory' of acids.

(*c*) Although not actually the discoverer of Iodine, he was one of the first to investigate it, and classified it as an element. He pointed out its similarity to chlorine,

and predicted the discovery of another similar element, Fluorine.

(*d*) By means of the electric current he decomposed the caustic alkalis, quick-lime, baryta, and magnesia. In this way he discovered the new metals sodium, potassium, calcium, and magnesium.

III

Chemical Theory

The Law of Conservation of Mass. The Law of Constant Proportions.	These were established before the Atomic Theory was advanced.

John Dalton (1766–1844)

(*a*) In 1808 Dalton published his famous Atomic Theory explaining chemical behaviour. All the chemical laws can be deduced from this theory and confirmed by experiment.

(*b*) He defined atoms and compound atoms (molecules) and atomic and molecular weights. During the next sixty years the majority of chemists devoted their energies to the determination of atomic and molecular weights. This finally led to a complete scheme of classification of the elements based on their atomic weights.

Organic Chemistry

(1) It was found that the majority of organic substances contain the elements carbon, hydrogen, and oxygen.

(2) 1828. Wöhler 'synthesised' urea.

(3) The molecules of organic compounds were found to be extremely complicated, but always contained a 'skeleton' of carbon atoms.

(4) Methods were devised for changing the atom or groups of atoms attached to a carbon atom of the skeleton. This made possible the synthesis of a very great number of organic compounds.

SUMMARY TO CHAPTER XI

I

Thales

The earliest of the Greek Philosophers. He investigated the properties of amber and of the magnetic stone.

The Mariners' Compass

This first began to be used in the eleventh century.

Peter Peregrinus

He first defined the Poles of a Lodestone.

Dr William Gilbert (1544–1603)

He was the true founder of the sciences of Magnetism and Electricity.

(*a*) He thoroughly investigated the properties of a magnet.

(*b*) He showed that the Earth was itself a huge magnet.

(*c*) He produced electricity by friction and distinguished between electrics and non-electrics.

II

Dufay (1699–1739)

He recognised that there were two kinds of electricity, vitreous and resinous. He found that like kinds repel each other, but unlike kinds attract each other.

The Leyden Jar

This was invented by a Dutch professor to store electricity. Electric sparks could be drawn easily from such a jar, which also produced a severe shock when discharged through a human body.

Electrical Machines

Various types were invented during the eighteenth century.

Benjamin Franklin (1706–1790)

(*a*) He suggested the theory that there was only one kind of electricity. Positively charged (vitreous) bodies have an excess, and negatively charged (resinous) bodies have a deficiency of electricity.

(*b*) He showed that lightning was an electrical discharge, either between two thunder-clouds, or between a thunder-cloud and the earth.

The Hon. Henry Cavendish (1731–1810)

(*a*) He began to measure electrical quantities.

(*b*) He defined 'electrical capacity' and 'degree of electrification' (electrical potential).

(*c*) He made condensers.

(*d*) He determined the conducting power of various substances.

III

Luigi Galvani (1737–1789)

He discovered what he called 'animal electricity.' This was discharged when two different metals in contact were joined by a frog.

Alessandro Volta (1745–1827)

(*a*) He maintained that so-called animal electricity was generated by the two different metals in contact. He substituted other non-living moist conductors for the frog and obtained a discharge.

(*b*) He constructed the famous 'Voltaic Pile' which gave the first *continuous* current.

(*c*) He made the first simple cell.

Hans Christian Oersted (1777–1851)

He discovered that a magnetic field is produced around a wire carrying a current of electricity.

Andre Marie Ampère (1775–1836)

He showed mathematically how to calculate the strength of an electric current from the magnetic field which it produced. (1) Galvanometers, and (2) the Electric Telegraph are the direct result of Ampère's work.

George Simon Ohm (1789–1854)

He defined Electromotive Force (E. M. F.) and Resistance.

Ohm's Law:— $\frac{E}{C} = R$.

IV

Michael Faraday (1791–1867)

(*a*) He explained the attraction and repulsion of magnetic poles and electric charges by supposing the existence of lines of magnetic and electric force.

(*b*) He discovered Electro-magnetic Induction, *i.e.* a change in the strength of the magnetic field round a conductor produces a current in the latter *while the change is taking place*.

Some practical applications of this are:

(1) The dynamo.
(2) The electric motor.
(3) The telephone.

(*c*) He investigated the chemical action of the electric current. These experiments led eventually to:

(1) the realisation of the electrical nature of chemical action; and
(2) to the industry of electro-plating.

James Clerk Maxwell (1831–1879)

(*a*) He produced mathematical evidence in support of Faraday's discoveries.

(*b*) He showed that light was 'electromagnetic' in nature.

(*c*) He predicted the discovery of wireless waves.

SUMMARY TO CHAPTER XII

I

The Ancient World

Human and animal power alone were used to lift and transport all loads.

Archimedes (287–212 B.C.)

He first constructed machines, in the shape of pulleys and levers, as an aid to human power.

Leonardo da Vinci (1452–1519)

His notebooks are full of drawings of mechanical devices.

Evangelista Torricelli (1608–1647)

(*a*) He first explained satisfactorily the working of a suction-pump.

(*b*) He constructed the first barometer by which he demonstrated and measured the pressure of the atmosphere.

Blaise Pascal (1623–1662)

He planned, and his brother-in-law, Perrier, carried out, an experiment which confirmed Torricelli's opinion as to the tremendous pressure of the atmosphere. This experiment showed the possibility of measuring heights by use of the barometer.

Otto von Guericke (1602–1686)

(*a*) After many efforts, he succeeded in obtaining a vacuum.

(*b*) He invented the first air-pump.

(*c*) He demonstrated in a spectacular fashion the tremendous pressure of the atmosphere.

II

The Steam-Engine

Dionysius Papin (1647–1712)

He designed the steam-engine, but was never able to obtain a satisfactory working model. The engine worked under the power of atmospheric pressure.

Thomas Newcomen

He was an English iron worker who carried out Papin's plans, and in 1711 constructed the first working steam-engine, which was used to pump water out of mines. It was very expensive to work, on account of the amount of fuel consumed.

James Watt (1736–1819)

By fitting Newcomen's engine with a condenser he reduced the necessary amount of fuel and so made the steam-engine a practical proposition. It could now be used for a variety of purposes.

Watt's 'low-pressure' engine has now been superseded by the 'high-pressure' engine.

III

The Internal Combustion Engine

1. The first of these engines used coal gas and air as fuel.

2. The first successful petrol-engine was constructed by *Gottlieb Daimler*. His engines were fitted to boats and then to carriages, thus ushering in the age of the motor-car.

3. *Count Zeppelin* in 1900 constructed the first airship to which a petrol-engine was fitted.

4. *Wilbur and Orville Wright* were the pioneers in aeroplane construction. In 1903 they made a machine, fitted with a petrol-engine, which flew 260 yards.

SUMMARY TO CHAPTER XIII

I

Heat

Nature of Heat

The old conception of heat was of a weightless, invisible fluid of definite substance. *Lavoisier* called it Caloric and placed it in his list of elements.

Effects of Heat

(1) Chemical.

(2) Expansion.

Galileo used (2) in making the first thermometer.

Latent Heat

(1) This was first recognised by Dr Joseph Black as the heat which disappears when a solid melts or a liquid boils.

(2) Black also devised a method for measuring latent heat, which is still used.

Units of Heat

The modern units of heat are:

(1) *The Calorie,* which is the amount of heat required to raise the temperature of 1 grm. of water through 1° C.

(2) *The British Thermal Unit* (B.T.U.), which is the amount of heat required to raise the temperature of 1 lb. of water through 1° F.

(3) *The Therm,* which is equal to 100,000 B.T.U.

Heat Capacity

Different substances require different amounts of heat to raise their temperature by the same amount. Water has the greatest heat capacity of all.

Heat a Form of Motion

(1) *Count Rumford* succeeded in boiling water by the heat produced by friction when boring a brass cannon with blunt tools.

(2) *Sir Humphry Davy* melted wax by rubbing two bits together, although the temperature of the surroundings was kept below the melting-point of ice.

In both (1) and (2) the only thing supplied externally was motion. Both Rumford and Davy, therefore, concluded that heat was a form of motion.

(3) *Julius Robert Mayer* (1814–1878) realised that other forms of energy could be transformed into heat. He showed that the difference between the work put into a machine and that taken out appeared as heat caused by the friction of the parts of the machine.

(4) *James Prescott Joule* (1818–1889) first determined the Mechanical Equivalent of Heat. He devised a great number of ways to do this.

The Principle of Conservation of Energy

This states that no Energy is ever lost or created. If it apparently disappears in one form it will simultaneously reappear in another. This principle was established by the work of Mayer and Joule.

II

Sound

The Greeks

They knew that sound was caused by vibration and that air was necessary for its transmission. Pythagoras founded the science of music.

Leonardo da Vinci (1452–1519)

(1) Sound travels in waves through the air.

(2) An echo is caused by the reflection of sound waves from a hard, smooth surface.

Sir Isaac Newton (1643–1727)

(1) He investigated and described wave motion fully.

(2) He showed how to calculate the velocity of sound in air when the density, temperature, pressure, and humidity of air were known.

III

Light

Properties of Light known in Newton's Time

(1) It travelled in straight lines.

(2) The Law of Reflection was known.

(3) The Law of Refraction was known (Snell).

(4) The velocity of light had been determined by Roemer.

(5) White light could be decomposed into seven colours by passing through a prism (Newton).

Isaac Newton

He upheld the Emission or Corpuscular Theory of Light.

(1) Light consists of streams of tiny fast-moving particles.

(2) These travel in straight lines.

(3) They are reflected from surfaces according to the law of reflection.

(4) They travel at different speeds in different media, and the path is, therefore, bent (Refraction).

Christian Huyghens (1629–1695)

(1) He objected to the Emission Theory on the grounds that the particles in two streams of light which met would collide. In practice they were known not to interfere with each other.

(2) As an alternative, he advanced the 'Wave Theory of Light.' According to this, light travelled in waves in the same way as sound. Since it was known to pass across a vacuum, he supposed the existence of the ether which could vibrate.

Newton objected to the Wave Theory, because, if true, light should spread slightly round corners. Thus shadows from a point source should have blurred edges. They apparently did not.

N.B.—Owing to the authority of Newton in the world of scientists, the Emission Theory was held universally until the beginning of the nineteenth century.

Thomas Young (1773–1829)

He studied carefully both theories of light and devised an experiment to decide between them.

This experiment decided in favour of Huyghens' Wave Theory. Owing to the opposition of Lord Brougham, little notice was taken of his work.

Augustine Fresnel (1788–1827)

(1) He obtained the same result as Young twelve years later, and quite independently. He added mathematical proof to the experimental one. On the publication of his work, the Wave Theory was universally accepted.

(2) He showed that light vibrations are transverse and not longitudinal.

IV

The Spectrum

The Corpuscular Theory

explained the different colours of the spectrum by supposing a difference in size in the particles. Red rays contained the largest particles and violet the smallest.

The Wave Theory

supposed a difference in wave-length between the rays of different colours. Violet light has the shortest wave-length and red the largest.

Radiant Heat (1800)

Sir William Herschel (1738–1822) discovered the existence of Radiant Heat Waves (or Infra Red Rays) beyond the red end of the spectrum.

Ultra-violet Rays (1801)

These were next discovered beyond the violet end of the spectrum. These are absorbed by ordinary glass.

X-Rays (1895)

These were discovered by *Professor Röntgen.* They consist of waves of very short wave-length indeed. The shortest X-rays—often known as Becquerel rays—are given off from all radio-active substances.

Wireless Waves (1887–1901)

The possibility of these was predicted by Clerk Maxwell. They were first produced by *Heinrich Hertz* in 1887 and put to practical use by *Marconi* in 1901. Wireless waves are the longest waves known. The wave-length varies from about 1 centimetre to 2000 metres.

SUMMARY TO CHAPTER XIV

I

Sir William Herschel (1738–1822)

(*a*) He became expert at constructing very large powerful reflecting telescopes.

(*b*) During his lifetime he carried out four detailed and systematic surveys of the heavens. In this way he discovered variable and double stars and many nebulæ.

(*c*) In 1781 he discovered a new planet which was named Uranus.

(*d*) He further discovered that the stars were not fixed but were moving, often at great speeds.

(*e*) Finally, he arrived at the conclusion that the sun was by no means the centre of the universe nor the largest heavenly body.

Pierre Simon Laplace (1749–1827)

(*a*) By applying the Law of Gravitation he was able to determine the effect of the planets on each other. In this

way he was able to account for a discrepancy between certain calculations of Newton's as to the positions of planets in the past and the records of actual observations of these positions.

(*b*) He showed that the solar system was in equilibrium.

(*c*) He put forward his 'Nebular Hypothesis' to account for the formation of the Solar System. This is not the explanation given to-day.

John Adams (1819–1892) *and Jean Joseph Leverrier* (1811–1877)

From the deviations of Uranus from the path calculated according to the Law of Gravity, these two men independently calculated the position of a seventh, as yet unknown, planet which was causing these deviations. The new planet was found in the calculated place and was called Neptune.

II

The Velocity of Light:

Olaus Roemer (1644–1710)

From observations of the eclipses of one of Jupiter's moons he calculated the velocity of Light and found it to be approximately 186,000 miles per second.

Armand Hippolyte Louis Fizeau (1819–1896)

In the nineteenth century, with very sensitive apparatus, he confirmed Roemer's figure for the velocity of light. His source of light was artificial and his distances comparatively small.

The Distances of the Stars:

Hipparchus of Nicea (*Second Century* B.C.)

This Greek astronomer was the first to attempt to measure the distance of the sun and moon from the earth.

The Arabians

Their astrologers greatly improved astronomical instruments so that these distances were more easily and accurately measured.

Sir William Herschel

He tried to apply the old methods in finding the distances of the fixed stars, but failed.

Frederich Wilhelm Bessel (1784–1846)

In 1838, using a heliometer, he succeeded where Herschel had failed. The distances of the stars from the earth and from each other are very great indeed. The unit of measurement for these distances is the light-year.

III

Spectrum Analysis

The Composition of the Sun and Stars:

Josef Fraunhofer (1787–1826)

(*a*) He was a very famous instrument-maker.

(*b*) He brought about a great improvement in the manufacture of glass used for prisms, mirrors, and lenses in these optical instruments.

(*c*) With one of his new prisms he obtained a spectrum from the sun's light which was crossed with dark lines. He found similar lines in the spectrum from Venus and from certain fixed stars. He made careful drawings of the positions of these lines.

Robert Wilhelm Bunsen (1811–1899)

(*a*) He showed that elements in the glowing gaseous state give 'line spectra.'

(*b*) He examined and mapped the spectra of a great number of elements.

Gustav Kirchoff (1824–1887)

(*a*) He found that, if white light is passed through hot gases or vapours, the particular kind of light emitted by the gas alone is now absorbed. Thus, if a spectrum of the white light is obtained after it has passed through the vapour, it is crossed by dark lines. These correspond in position to the line spectrum of the gas.

(*b*) He found that the dark lines in the sun corresponded to elements whose line spectra had been mapped by Bunsen. He was thus able to identify elements present in the vapour of the sun.

Examination of the spectrum of light from a star also gives information concerning:

(1) its temperature,

(2) its motion towards or away from the earth.

SUMMARY TO CHAPTER XV

I

Aristotle

(*a*) He studied for himself many kinds of living things.

(*b*) He wrote down in his book many of the writings of earlier men concerning plants and animals.

Galen (A.D. 130–200)

(*a*) He was a Roman doctor who collected together in a book all the knowledge of his time concerning human anatomy. This knowledge was gained from the study of apes and dogs rather than humans.

(*b*) His book became the great 'Authority' for the doctors of the Middle Ages.

Anatomy:

Vesalius (1514–1564)

(*a*) He was an Italian Professor of Anatomy who, contrary to custom, carried out the dissections of the human body to illustrate his lectures.

(*b*) In this way he discovered that many of the teachings of Galen were false, being founded on the study of apes and dogs instead of humans.

(*c*) He published a book on the Anatomy of the Human Body, which laid the foundation of modern anatomy.

Physiology:

William Harvey (1578–1667)

He carried out the first experiments in *Physiology* by establishing the fact of the Circulation of the Blood He showed:

(*a*) that the blood could only flow one way in the veins, because of the valves;

(*b*) by measuring the quantity of blood leaving the heart in a given time, that it circulates round the body and comes back again to the heart;

(*c*) that the blood leaves the left side of the heart by the arteries and returns to the right side by the veins.

(*d*) that the blood travels from the right side of the heart to the left side by way of the lungs.

Johannes Müller (1774–1842)

(*a*) He had a famous laboratory at Berlin where, with his students, he carried out extensive investigations in Physiology.

(*b*) He invented many different kinds of apparatus with which to carry out these investigations.

II

Discoveries with the Microscope

Marcello Malpighi (1628–1694)

(*a*) He examined the air passages in the lungs and saw the tiny blood-vessels connecting the veins and the arteries.

(*b*) He discovered the red corpuscles in the blood.

(*c*) He found several layers to the skin.

(*d*) He studied the anatomy and the life-history of the silkworm, and discovered the mechanism by which it produces silk.

(*e*) He studied and made the first drawings of plant cells.

Jan Swammerdam (1637–1680)

(*a*) He made an especial study of insects, and became very skilled in dissecting them and examining them under the microscope.

(*b*) He made very beautiful drawings of what he found.

Anthony van Leeuwenhoek (1632–1723)

(*a*) He examined a very great variety of things under his microscopes, which he made himself.

(*b*) He also discovered the capillaries connecting arteries and veins. He first saw them in the tail of a tadpole.

(*c*) He discovered the Protozoa in pond water and found that they continued to live when the water dried up.

Schwann

(*a*) He maintained that the unit from which all living things were built was the cell.

(*b*) He thought, wrongly, that the most important thing about the cell was its wall.

Max Schultze

He showed that the essential part of the cell was the protoplasm, since some animal cells have no wall.

Redi

(*a*) He showed that the maggots which always appeared in decaying meat did not spring spontaneously from the decay, but were hatched from eggs which flies had laid on the meat.

(*b*) He further showed that, in all cases where life apparently sprang from dead matter, germs of life had somehow been introduced.

Louis Pasteur (1822–1895)

(*a*) He showed that bacteria are floating everywhere in the air, but that pure country or mountain air contains far fewer than the air in cities and inside houses.

(*b*) He discovered that the fermentation of sugar to produce alcohol, the souring of milk, and the growth of a mould on cheese were each due to the action of a particular kind of bacteria. With his microscope he identified these bacteria in each case.

(*c*) He found that the cause of silkworm disease was due to a germ, and showed how the disease could be combated.

(*d*) He introduced the use of vaccines as a preventative against certain forms of infectious diseases.

(*e*) The Pasteur Institute in Paris was built to enable the study of Bacteriology to be carried on.

Robert Koch

(*a*) He was a contemporary of Pasteur and discovered the germs of Anthrax in the blood of sheep suffering from the disease. This was the starting-point of Pasteur's work on vaccines.

(*b*) He also discovered the germ producing tuberculosis and cholera.

Jenner (1749–1823)

He was responsible for the introduction of vaccination against smallpox.

Sir Joseph Lister (1827–1912)

He introduced the antiseptic method into surgery. This he did as a result of Pasteur's work.

III

The Relationship between the Various Forms of Life

Aristotle

He made the first attempt at classification, but dealt chiefly with animals.

Karl Linnæus (1707–1778)

He introduced the system of classification which is used in much the same form to-day.

Georges Cuvier (1769–1832)

(*a*) He studied as many different types of animals as possible, and compared their structures and the functioning of their organs. This study is known as Comparative Anatomy.

(*b*) He examined the fossils in the gypsum mines, near Paris, and discovered that some of the bones belonged to animals no longer known on earth (extinct).

(*c*) After many years spent in studying fossils he came to the conclusion that at certain times some types of animals became extinct, and new ones were formed.

(*d*) He believed these changes to be due to catastrophes such as widespread flood.

Jean Baptiste Lamarck (1749–1829)

(*a*) He also studied fossil remains, but confined his attention chiefly to invertebrates.

(*b*) He disagreed with Cuvier in thinking that certain forms died out and were replaced by others at certain well-defined times. He was of the opinion that the changes were very gradual and that there was a succession of closely related types to be found.

(*c*) He was confirmed in this opinion by the discoveries of the English geologist *William Smith*. The latter found that the surface layer of the earth is made up of a number of strata which always appear in the same order. These strata are characterised by the fossils which they contain. Fossils in one layer often show small but quite definite differences from similar fossils in the nearest layer of the same kind.

(*d*) To explain this evidence of the existence of succession of forms of life he advanced the theory of Evolution by Inheritance of Acquired Characteristics.

N.B.—The theory of evolution is now generally accepted, but not Lamarck's particular explanation that it occurred by the inheritance of acquired characteristics.

Charles Lyell (1797–1875)

(*a*) He was an English geologist.

(*b*) By studying the changes which are going on in the earth's crust now, he tried to understand the changes which have taken place in the past.

(*c*) In this way he explained the formation of layers and the fossils found embedded in them.

(*d*) By studying the rate at which layers are now being built up he was able to calculate the period of time in which any given stratum was laid down. In this way he fixed definite eras during which certain forms of life existed.

Charles Darwin (1809–1882)

(*a*) He went round the world in H.M.S. *Beagle* as Naturalist. In this way he collected an enormous number of specimens on the study of which his future work was based.

(*b*) The study of these specimens convinced him of the fact of Evolution.

(*c*) The explanation he gave differed from that of Lamarck. It is generally known as Natural Selection by the Survival of the Fittest.

(*d*) He published his evidence for Evolution, together with his explanation as to how it came about, in his famous book *The Origin of Species.*

IV

Heredity

(1) New organisms are formed by the fusion of male and female gametes.

(2) Male gametes are small and easily detached from the parent (*e.g.* pollen grains).

(3) Female gametes are larger and remain attached to the parent (*e.g.* ovules).

(4) The fusion of a male with a female gamete is known as fertilisation and produces a Zygote.

Gregor Mendel (1822–1889)

(*a*) He studied the inheritance of certain characteristics of garden peas of which he grew several generations.

(*b*) He came to the conclusion that characteristics usually go in opposite pairs. He called these 'factors.'

(*c*) He supposed that any one gamete can only carry *one* of a pair of factors.

(*d*) He further came to the conclusion that, in any pair of factors, one was 'dominant' and the other 'recessive.'

(*e*) Any zygote carrying both factors of a pair will itself show the characteristic of the dominant factor, although it may pass on the recessive character to its offspring. Only zygotes carrying a double dose of the recessive factor exhibit the corresponding characteristic.

SUMMARY TO CHAPTER XVI

A. *The Inside of the Atom :*

(*a*) The atom consists of a heavy positive nucleus surrounded by rings of electrons.

(*b*) The greater part of the bulk of an atom is empty space.

(*c*) Atoms of elements heavier than lead and bismuth are unstable. These elements are known as radio-active elements.

(*d*) *Becquerel* discovered Uranium, and *M. and Mme Curie* discovered Radium.

(*e*) *Professor Soddy* investigated the disruption of the nucleus of radio-active substances. Three kinds of radiations are given off:

(1) *Alpha Rays*—particles which carry a positive charge.

(2) *Beta Rays*—particles which are electrons and therefore negatively charged.

(3) *Gamma Rays*—which are really very short X-rays. They are known as Becquerel Rays.

(*f*) *Lord Rutherford*, by bombarding certain gases with alpha particles, succeeded in knocking bits off some of the nuclei and so forming another kind of element.

B. *Exploring the Universe:*

(*a*) *Professor Einstein* has shown that Newton's Laws do not hold accurately in the vastness of the universe; nor in the minute world of the atom.

(*b*) He has supplied others in their place.

C. *Modern biologists are working along three main lines:*

(1) The study of Heredity.

(2) The study of the Laws of Health.

(3) The study of the Human Mind.

SUBJECT INDEX

INDEX OF NAMES